Kees Stigter (Ed.)

Applied Agrometeorology

Springer

Applied Agrometeorology

Kees Stigter
Editor

Applied Agrometeorology

Springer

Editor
Kees Stigter
Groenestraat 13
5314 AJ Bruchem
and
P.O. Box 16
68208 Bondowoso
Agromet Vision
Netherlands and Indonesia
cjstigter@usa.net

ISBN 978-3-540-74697-3 e-ISBN 978-3-540-74698-0
DOI 10.1007/978-3-540-74698-0
Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2010925334

Cover illustrations: Taking leaf and soil samples in mulching experiments in alley cropping research at the KARI Dryland Research Station, Machakos, eastern Kenya, with agriculture on sloping lands in the background (top over whole page and below that in the centre); Nomads with their animals and sedentary farmers using the same area between shelterbelts in Yambawa, northern Nigeria. Only differentiation between their needs and sustaining complementarity of their lifestyles in a changing climate will prevent resource conflicts (below top, right hand side); Adding shades to protect traditional grain storage bins from moisture influx due to solar radiation on previously wetted bin walls at the Uyole Experiment Station, Mbeya, southern Tanzania (below top, left hand side). [Photos Kees Stigter]

Cover design: deblik, Berlin

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

I recently presented an invited paper "Rural response to climate change in poor countries: ethics, policies and scientific support systems in their agricultural environment" at an International OECD Policy Conference at the University of Wisconsin, Madison (USA), 29 June till 1 July 2009, on "Sustaining soil productivity in response to global climate change: science, policies and ethics". One of my conclusions was that (external) ethics is these days a (rare but) thoroughly accepted reason to decide to work in and for developing countries in Africa, Asia, Latin America. I took that decision more than 40 years ago. This ethical choice was based on my own suffering from the poverty that I had witnessed during early travels (in the 1960s) in these three continents.

Intuitively applying an interpretation of the Buddhist philosophy of the four Noble Truths (e.g. Brazier 1997), I learned that one can respond to such personal affliction by this rural suffering from physical and socio-economic (environmental) disasters in a practical way. Going the eightfold path of the right view (of ourselves), the right thought (of higher purpose), the right speech (of the vow of aspiration), the right action (of being part of a big story), the right livelihood (lifestyle), the right effort (intensity), the right mindfulness (remembrance and transcendence) and the right (transformative) vision. In doing so, one's private suffering may be diminished as well.

Kees Stigter

Reference

Brazier D (1997) The feeling Buddha. Robinson, London, 207pp

Preface

The contents of this book are meant to assist applied agricultural scientists in learning from case studies and other background material how to apply agrometeorology better to solve problems in the livelihood of farmers and other agricultural producers. It also wants to create a renaissance in the teaching (that is education/training/extension) of applied agrometeorology at all levels, closer to the livelihood of farmers and other agricultural producers.

Agrometeorological services are therefore the ultimate focus of this book and applied agrometeorology is shown in the service of farmers, forest and agroforestry related practitioners, and other stakeholders in using an agricultural environment to get enough and better food, fodder, fibre and other natural products.

Early in the course of 40 years of international research, teaching and consultancy, particularly in the non-industrialized world, and more than 20 years of elected international leadership (WMO, INSAM) in agrometeorology, I had become fully convinced that applied agrometeorology should actually be dealt with along different lines.

A WMO educational meeting in New Delhi early in 2007 (see Part I of this book) gave me the opportunity to test some of my ideas with some also invited colleagues from various parts of the world that would advise on new curricula in agrometeorology. They agreed with my proposal to abandon the entry towards Applied Agrometeorology through Basic Agrometeorology and to find entries for it of its own.

Once we had agreed on this basic dichotomy, that meeting designed and approved "Strategic Use of Climate Information", "Coping with Climate Variability and Climate Change", "Coping with Extreme Meteorological Events", "Tactical Decision Making Based on Weather Information" and "Developing Risk Management Strategies" as the present main entry paths to Applied Agrometeorology.

On my way back from New Delhi to Indonesia, waiting for new visa in Singapore, I finalized among others curricula contents under these headings in the form of postgraduate syllabi in an earlier agreed format. I made use of my own earlier ideas and they were later on generally approved by the other New Delhi participants in e-mail contacts. I have to note that I do not like the terminology of "risk management" for small farmers, that generally try hard to cope with their environmental difficulties more than that they manage them. These syllabi are given in their original form in Annex I.I of Part I of this book. This shows that much historical material needed for new policies would also be collected in writing these syllabi. This is particularly also fully in line with the Sect. II.D on "Communication approaches in applied agrometeorology".

As indicated in Part I, for that part of these syllabi in which a link with basic agrometeorology is made, material has been collected in Part III of this book. It must show bedrock material for existing or new agrometeorological services. Within local agrometeorology, so on the scale of agricultural fields, this book wants to follow an approach in which actual problems in the livelihood of farmers are shown to be solvable using purely applied science. The latter should be supported by the methods, as tools and approaches, of Part IV, that belong to the basic science support systems.

It should be noted from the agrometeorological services examples collected in Part II that so far the knowledge input into these services is in many cases relatively simple but the complications are in the communications. In collecting and writing the contents of Part III, this has been taken into account. But it means that the enormous amount of material collected may be expected to be a powerful source of tools and approaches for the design of agrometeorological services in many problem fields for a long time to come, scientifically supported by the directions of the contents of Part IV. The context in which we collected the material as agrometeorologists should stimulate the design of more and better agrometeorological services.

In this Part III, the choice of the various subjects, derived from the proposed subdivision of the syllabi under the five headings mentioned above, is fully mine. Their contents are a first approach to the syllabi and determined by the various authors that have written about these subjects. In all cases these authors had been given an example of the proposed approach in the form of respectively Sects. III.2.3.(A), III.3.3.(A), III.4.3.(A), III.5.3.(A), III.6.A.(i), III.6.B.(i) and III.6.C.(i) with the title: "Problems and solutions in coping with extreme meteorological events in agricultural production and challenges remaining for the use of science to contribute to problem analyses and designing valuable solutions in this context" for the respective fields of (i) monocropping, (ii) multiple cropping, (iii) forestry, (iv) non-forest trees, (v) animal husbandry, (vi) cropping under cover and (vii) fisheries.

I am also stating in Part I that once such courses will materialize, it will appear to be information also needed in designs of further adaptation strategies and policies. Good Ph.D.-, M.Sc.- and B.Sc.-thesis research subjects can be designed for increasing the numbers and improving the contents of documented case studies, because often the available information will need extension, adaptation and updating. This is one way in which research can become more relevant to problem solving and problems related teaching and can help improve them. Local knowledge collection will also help in tying research and teaching to meteorological disaster impact experience and to improved preparedness of farmers in different land use and cropping patterns.

After all, it are these thorough links between practice, education/training/ extension, policies, research and science in agricultural production that make applied agrometeorology relevant and valuable, if and when the right ethical choices have been made.

Bruchem, The Netherlands Kees Stigter
August 2009

Acknowledgments

This book is far from a one man's exercise. There are 113 contributors to Parts II, III and IV, of which 40 in the protocols of Part II, 40 in Part II (outside the protocols) and Part III together, and 36 in Part IV, with little overlap. I consider their participation as indispensable and most valuable. I wrote Part I all alone, was editing all 30 protocol contributions to Part II and was a co-author in 10 of them. I was involved as author, co-author or advisor (as Kees Stigter or C.J. Stigter) in more than 70 of the 120 contributions to Parts II (outside the protocols), III and IV. I edited all contributions together with their (co-)authors.

As to Part II, I developed the protocol and I had the privilege to be able to use material we collected and assessed in this form in the annual INSAM contests. Although the CMA/CAU/APMP project is far from finalized, I am happy that I was able to have here a draft version of ten protocols that I could edit from an early translation by a team headed by Xiao Hongxian within the CMA. This was just sufficient to show and discuss the value of this material, even when not final. I am thankful to CMA and CAU for the support received.

In Part III there were 29 other fine authors, but two stand out in contributing to more than 10 chapters. Dr. H.P. Das and Dr. Kulasekaran Ramesh brought this way into the book an important flavor from Asia and what is important there, for which my particularly deep thanks. From four to six contributions were delivered by Drs. Emmanuel Ofori, Nicholas Kyei-Baffour and Sue Walker, from Africa, to the part on multiple cropping; by Dr. Al Riebau to the part on forest (agro)meteorology; by Drs. Luigi Mariani and Osvaldo Failla to the part on non-forest trees; and by Dr. John Gaughan to the part on animal husbandry. Without these nine multi-chapter authors, this book would also not have its present form and contents. The other 20 authors particularly also contributed to the great variation in material collected for use in the design of all kinds of agrometeorological services thinkable.

In Part IV, 15 lead authors and 21 co-authors took part in bringing scientific contributions as support systems close to applications in agrometeorology, illustrating very important methods, as tools and approaches, in exercises themselves important in the design of agrometeorological services.

I have worked for more than $3\frac{1}{2}$ years to think, get and build these contributions together in one major plan, to show the extent of applied agrometeorology when viewed from the angles of services to be established in the livelihoods of farmers and other agricultural producers. May through our joint efforts in this book many agrometeorologists now get a better feeling for what is possible in applying agrometeorology this way.

Bruchem, The Netherlands Kees Stigter
August 2009

Contents

III.2 APPLIED AGROMETEOROLOGY OF MONOCROPPING IN THE OPEN

III.2.1 Strategic Use of Climate Information

III.2.2 Coping with Climate Variability and Climate Change

III.5 APPLIED AGROMETEOROLOGY OF NON-FOREST TREES

III.5.1 Strategic Use of Climate Information

III.5.2 Coping with Climate Variability and Climate Change

III.6.B Cropping Under Cover

III.6.C Other Aspects: Fisheries and Aquaculture, Urban Agriculture, Precision Farming

PART IV METHODS AS TOOLS AND APPROACHES SUCCESSFULLY USED IN APPLICATIONS LEADING TO AGROMETEOROLOGICAL SERVICES

Contributors

Ernesto G. Abril CREAN, Universidad Nacional de Córdoba – CONICET, Córdoba, Argentina, egabril@crean.agro.uncor.edu

M. Acunzo Research and Extension Division, FAO, Rome, Italy, mario.acunzo@fao.org

M.H. Ali Bangladesh Institute of Nuclear Agriculture, Mymensingh, Bangladesh, hossain.ali.bina@gmail.com

S. Baas Environment, Climate Change, and Bioenergy Division, FAO, Rome, Italy, stephan.baas@fao.org

Gianni Bellocchi Monte Pino Met European Research Observatory, GTOS\TEMS Network, Benevento, Italy, g.bellocchi@isci.it

M. Bernardi Environment, Climate Change, and Bioenergy Division, FAO, Rome, Italy, michele.bernardi@fao.org

Gerard P.A. Bot Retired from Wageningen University and Wageningen UR Greenhouse Horticulture, Wageningen, The Netherland, gerardenvera.bot@hetnet.nl

Claude E. Boyd Department of Fisheries and Allied Aquacultures, Auburn University, Auburn, AL, USA, boydce1@anburn.edu

Orivaldo Brunini IAC, Campinas, São Paulo, Brazil, brunini@iac.sp.gov.br

Paulo Henrique Caramori IAPAR, Londrina, Paraná, Brazil, caramori@iapar.br

Michele Ceccarelli Research Center on Software Technologies-RCOST, University of Sannio, Benevento, Italy, ceccarelli@unisannio.it

Andrew Challinor University of Leeds, Leeds, UK, a.j.challinor@leeds.ac.uk

H.P. Das Retired from Indian Meteorologidal Department, Pune, India, hpd_ag@rediffmail.com

Marcelo Bento Paes De Camargo IAC, Campinas, São Paulo, Brazil, mcamargo@iac.sp.gov.br

Pedro Luiz De Freitas Embrapa Soils, Rio de Janeiro, Brazil, freitas@cnps.embrapa.br

Dalziza De Oliveira IAPAR, Londrina, Paraná, Brazil, dalziza@iapar.br

Glauco De Souza Rolim IAC, Campinas, São Paulo, Brazil, rolim@iac.sp.gov.br

Marjolein De Weirdt EARS B.V., Delft, The Netherlands, marjolein.weirdt@ears.nl

Justin D. Derner USDA-Agricultural Research Service, Cheyenne, WY, USA, justin.derner@ars.usda.gov

Raymond L. Desjardins Agriculture and Agri-Food Canada, Ottawa, ON, Canada, desjardins@agr.gc.ca

Nazzareno Diodato TEDASS-Technological Interdepartmental Center for Environmental Diagnostics and Sustainable Development, University of Sannio, Benevento, Italy, nazdiod@tin.it

Julian Dumanski Retired from Agriculture and Agri-Food Canada and World Bank, Ottawa, ON, Canada, jdumanski@rogers.com

Osvaldo Failla Department of Crop Science, University of Milan, Milan, Italy, osvaldo.failla@unimi.it

Dick Felch National Weather Service, NOAA (retired), Chanhassen, MN, USA, dickfmn@gmail.com

Steven Foppes EARS B.V., Delft, The Netherlands, steven.foppes@ears.nl

Janis Gailis University of Agder, Kristiansand, Norway, janis.gailis@uia.no

J.B. Gaughan The University of Queensland, Gatton, QLD, Australia, j.gaughan@uq.edu.au

Pierre Gerber FAO, AGAL, Rome, Italy, pierre.gerber@fao.org

R. Gommes Environment, Climate Change, and Bioenergy Division, FAO, Rome, Italy, rene.gommes@fao.org

Ajit Govind College of Forestry, Oregon State University, Corvallis, OR, USA, ajit.govind@oregonstate.edu

G.L. Hahn Hastings, NE, USA, lh64041@windstream.net

S. Jost Environment, Climate Change, and Bioenergy Division, FAO, Rome, Italy, Stephane.Jost@fao.org

H.H. Khalifa Al-Azhar University, Cairo, Egypt, khalifahhk@usa.net

Nicholas Kyei-Baffour Agricultural Engineering Department, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, nkyeibaffour@hotmail.com

Nicola Lacetera Dipartimento di Produzioni Animali, Universita Degli Studi Della Tuscia, Italy, nicgio@unitus.it

Rattan Lal Ohio State University, Columbus, OH, USA, lal.1@osu.edu

John N. Landers Zero Tillage Farmers Association for Brazilian Cerrado Region, Brasilia, Brazil, john.landers@uol.com.br

Nathaniel Logar John F. Kennedy School of Government, Belfer Center for Science and International Affairs, Harvard University, Cambridge, MA, USA, nat.logar@gmail.com

Ma Yuping China Academy of Meteorological Sciences (CAMS), China Meteorological Administration (CMA), Beijing, China, mayp@cams.cma.gov.cn

Luigi Mariani Department of Crop Science, University of Milan, Milan, Italy, luigi.mariani@unimi.it

Raymond P. Motha United States Department of Agriculture, Washington, DC, USA, rmotha@oce.usda.gov

E. Mukhala OSRO/SUD/620-1/MUL, FAO/EC, Juba, Sudan, elijah.mukhala@fao.org

Francesca Natali Interdepartmental Centre of Bioclimatology, University of Florence, Florence, Italy, francesca.natali@unifi.it

Ahmad Ainuddin Nuruddin Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, Serdang, Selangor, Malaysia, ainuddin@forr.upm.edu.my

Nguyen Van Viet Agrometeorological Research Centre (ARC), Institue of Meteorology and Hydrology (IMH), Hanoi, Vietnam, agromviet@hn.vnn.vn

Emmanuel Ofori Agricultural Engineering Department, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, oforiegh@yahoo.com

Akinyemi Gabriel Omonijo Department of Agricultural Technology, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria, akingab@yahoo.com

Tomáš Orfánus Institute of Hydrology, Slovak Academy of Sciences, Bratislava, Slovakia, orfanus@uh.savba.sk

Simone Orlandini Department of Agronomy and Land Management, University of Florence, Florence, Italy, simone.orlandini@unifi.it

Mário José Pedro Jr. IAC, Campinas, São Paulo, Brazil, pedro@iac.sp.gov.br

Olga C. Penalba Department of Sciences of the Atmosphere and Oceans, Faculty of Exact and Natural Sciences, University of Buenos Aires, Buenos Aires, Argentina, penalba@at.fcen.uba.ar

S. Ramasamy Environment, Climate Change, and Bioenergy Division, FAO, Rome, Italy, selvaraju.ramasamy@fao.org

Kulasekaran Ramesh IHBT(CSIR), Palampur, India; IISS(ICAR), Bhopal, India, ramechek@yahoo.co.in

Andres C. Ravelo CREAN/Universidad Nacional de Córdoba – CONICET, Córdoba, Argentina, ravelo@crean.agro.uncor.edu

Allen Robert Riebau Retired from USDA Forest Service Research and Development, Nine Points South Technical PTY LTD, Clarkson, WA, Australia, ariebau@ninepointsouth.com.au

Roger E. Rivero Vega Meteorological Services of Camaguey Province, Camaguey, Cuba, roger@cmw.insmet.cu

Mark Rosegrant International Food Policy Research Institute (IFPRI), Washington, DC, USA, m.rosegrant@cgiar.org

Andries Rosema EARS B.V., Delft, The Netherlands, andries.rosema@ears.nl

Thomas J. Sauer USDA-ARS, National Soil Tilth Laboratory, Ames, IA, USA, tom.sauer@ars.usda.gov

Gerald E. Schuman Retired from USDA-Agricultural Research Service, Cheyenne, WY, USA, jerryschuman2@msn.com

Tor Håkon Sivertsen Norwegian Institute for Agricultural and Environmental Research, Aas, Norway, tor.sivertsen@bioforsk.no

Alireza Sodagari Orchardist/Grower, Selling Agromet Systems in the Country, Shiraz, Iran, k536_project@hotmail.com

Henning Steinfeld FAO, AGAL, Rome, Italy, henning.steinfeld@fao.org

Roger Stern Statistical Services Centre (SSC), University of Reading, Reading, UK, r.d.stern@reading.ac.uk

Kees or C.J. Stigter Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (WageningenUR), Wageningen, The Netherlands, cjstigter@usa.net

Tibor Stigter Instituto Superior Técnico, Technical University of Lisbon, Lisbon, Portugal, tibor.stigter@ist.utl.pt

M.S.U. Talukder Bangladesh Agricultural University, Mymensingh, Bangladesh, head_iwm@yahoo.com

Conrado Tobón Universidad Nacional de Colombia, Sede Medellín, Colombia, ctobonm@unal.edu.co

S.E. Valtorta Investigadora CONICET INTA Castelar, Buenos Aires, Argentina, silvia_valtorta@yahoo.com.ar

Kees Van der Post For Agromisa Foundation, Wageningen, The Netherlands, vande83@hetnet.nl

Ernst Van Heurn For Agromisa Foundation, Wageningen, The Netherlands

Louis Verchot Center for International Forestry Research (CIFOR), Bogor, Indonesia, l.verchot@cgiar.org

Sue Walker Department of Soil, Crop and Climate Sciences, University of the Free State, Bloemfontein, South Africa, walkers.sci@ufs.ac.za

Wang Shili Research Center for Agrometeorology and Remote Sensing Application, China Academy of Meteorological Sciences (CAMS), China Meteorological Administration (CMA), Beijing, China, wangsl@cams.cma.gov.cn

Zheng Dawei Department of Agrometeorology, China Agricultural University (CAU), Beijing, China, zhengdawei44@263.net

About the Editor

Kees Stigter is a visiting professor in Africa and Asia, these days for Agromet Vision, the Netherlands and Indonesia. His initials C.J. stand for Cornelis Johan, but Kees is his call name.

Experimental physicist by education (Phys. Drs., Amsterdam, 1966) and agrometeorologist/-climatologist by profession (Ph.D. in agriculture, Wageningen, 1974), he became member of staff (from 2001 to 2005 guest scientist) of Wageningen (Agricultural) University, the Netherlands (1966–1975, 1985–2005 (ret.); from 1974 as an Associate Professor and from 1985 in addition as a Principal Project Supervisor (TTMI-Project) and Visiting Professor in Africa and Asia.

His first mission was to Africa in May–September 1969 as an FAO expert in climatology in Madagascar. He was resident Associate Professor (1975–1978) and Full Professor (1978–1985) at the University of Dar es Salaam (Tanzania) Physics Department, in the fields of agricultural physics and agricultural meteorology.

From 1985, for the Traditional Techniques of Microclimate Improvement (TTMI) Project, he was a Visiting Professor at the University of Gezira, Wad Medani, Sudan (Department of Environmental Sciences and Natural Resources) till 2005; the University of Nairobi, Kenya (Departments of Crop Science and Meteorology) till 1999; the University of Dar es Salaam, Tanzania (Department of Physics) till 1999; and (from 1991) the Ahmadu Bello University, Zaria, Nigeria (Departments of Geography and Soil Science), till 1999. Author of the Picnic model for research education in Africa in a total of more than 40 TTMI missions. Lead author of a book on the TTMI-Project (1995).

Involved in evaluation and other missions in higher education and institutional matters, including invited lectures, in 17 African countries from 1969 till the present: Algeria, Benin, Burkina Faso, Ethiopia, the Gambia, Ghana, Kenya, Madagascar, Morocco, Niger, Nigeria, Senegal, Sudan, Tanzania and Zambia. Most recent visits: to the Sudan in 2005, to South Africa in 2006 and 2008 and Lesotho in 2008.

Subject expert (1988–1991) and project management consultant (1991–1993) for FAO/WMO/UNDP/ICAR in establishing the Centre for Advanced Studies in Agricultural Meteorology (CASAM), Pune, India. Since 1997, twelve missions (on average of more than one month) to China for the Asian Picnic Model Project (APMP), including the China Agricultural University in Beijing, trying to jointly establish pilot projects on assessing and evaluating (institutionalization of) agrometeorological services with five provincial meteorological administrations. From 1999 onwards, for the same APMP, lectures at 10 Universities and Institutes in Indonesia, with early emphasis in Bogor and presently in Yogyakarta, three missions to Vietnam and one mission each to the Asian Disaster Preparedness Centre, Bangkok and to Fukuoka, Japan.

Three missions for Agromet Vision of respectively 1 month, 5 and 2 weeks to India (2004, 2006, 2007) in which more than twenty lectures at twelve institutes in five cities (of which several times in Hyderabad, Pune, New Delhi and once in Chennai/Madras and Coimbatore). Missions for an Asian Pacific Network Project to Hyderabad (India, 2006) and Dhaka (Bangladesh, 2008).

Former Vice-President (1986–1991) and President (1991–1999) of the World Meteorological Organization (WMO) Technical Commission for Agricultural Meteorology (CAgM). Lead author of two CAgM Reports (Nrs. 25 and 43) on Microclimate Management and Manipulation Techniques in Traditional Low External Input Agriculture. Founding president of the International Society for Agricultural Meteorology (INSAM), since 2001. Writes since 2003 the homepages of the INSAM web site (www.agrometeorology.org).

Author and co-author of more than 700 publications, of which 125 in peer reviewed journals and also close to 200 invited/selected ones in books/monographs/CD-ROMs etc. Co-author of a book on agrometeorology of multiple cropping (1993 (French); 1997 (English)). Leader of the CAgM Expert Team and Editor-in-Chief on writing the third edition of the WMO Guide to Agricultural Meteorological Practices (GAMP, WMO 134), on which he works since 1999. A draft, in which 180 scientists collaborated, was published in 2007 but after more than 2 years the final version is still under in-house editing in Geneva.

Developed from 2000 onwards in many lectures two Roving Seminars on "Agrometeorological services: theory and practice" and on "Agrometeorology and sustainable development", which he gave in Iran in 2005, in India in 2006, parts in Brazil and Venezuela in 2007 and again fully in South Africa in 2008, and one of them fully in Indonesia in 2009. This is planned to continue.

Works these days particularly on connecting agricultural sciences, environmental sciences, social sciences and extension services, proposing to use new educational commitments such as Climate Field Schools for farmers. To obtain a rural response to climate change through their own innovations and what these applied sciences have to offer through extension.

Bruchem, The Netherlands
August 2009

Part I
Introductory Part

I Introductory Part

Kees Stigter

I.1 Introduction to Part I

Applied agrometeorology should not start with agrometeorology but with the conditions of where it should be applied. Because such conditions in the livelihood of farmers differ tremendously even within a sub-region of a country and between farming systems in that same sub-region, we have always to deal with case studies (Stigter 1988a, 1992; Mungai et al. 1996; Stigter 2006a, 2009a; WMO 2010). We came to that same conclusion also again in a recent international consultative meeting in India on curricula in agrometeorology at all levels (WMO 2009).

My attempts as early as the mid-1990s to introduce this approach, based on my experiences in Africa and India, in curriculum exercises for the Department of Education of WMO failed. But a new generation of scientists, now facing new and unprecedented problems in agricultural production worldwide, under conditions of diminishing direct funding, starts to become convinced that the need for science can best be illustrated with examples of its successful applications. Applied agrometeorology is basically about problem solving with agrometeorological components in agricultural production (e.g. Mungai and Stigter 1995; Mungai et al. 1996; Stigter 2008).

Such case studies on famers' applications of agrometeorological services and information have to be collected locally by Universities, Research Institutes and National Meteorological and Hydrological Services (NMHSs). They are the three main players in generating knowledge from data and research for feeding education/training/extension as well as policies, which among them are ultimately the four support systems to public and commercial agrometeorological services (e.g. Stigter 2007a, 2009b).

This book should therefore be on case studies of how agrometeorology and agroclimatology are used (i) to prepare farmers for extreme events and (ii) to prepare farmers for the beneficial use of climate, both under the specific socio-economic

K. Stigter (✉)
Agromet vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_1,

conditions of different farming systems and different income groups (Stigter et al. 2007a; Rathore and Stigter 2007; WMO 2009). The latter issues make it necessary to emphasize from all points of view how farmers (can) cope with risks. Not only the risks from weather and climate related disasters, pests and diseases but also the risks they take by preparing themselves in certain ways and by applying the agrometeorological services (made) available or proposed.

Annex I.I holds my original version for postgraduate syllabi for applied agrometeorology most related to the above two preparative issues, that show the approach that will be necessary. In a somewhat different form this approach can also be found in WMO (2009). It is surprising to see that once the basic courses have been fully separated from the applied courses, the contents of the latter become very different from what they are at present. Much of the information to be collected for the lectures of such curricula has presently to be obtained from various unusual sources, both in the grey literature and orally (Baldy and Stigter 1997).

Once such courses will materialize, it will appear to be information also needed in designs of further adaptation strategies and policies. Good PhD-, MSc- and BSc-thesis research subjects can be designed for increasing the numbers and improving the contents of these case studies, because often the available information will need expansion, extension, adaptation and updating. This is one way in which research can become more relevant to problem solving and problems related teaching and can help improve them. Local knowledge collection will also help in tying research and teaching to meteorological disaster impact experience and to improved preparedness of farmers in different land use and cropping patterns.

As an introductory part of the book, below first a broad definition of agrometeorology is given the way it was developed during my roving seminars in developing countries (e.g. KNMI 2009). It was also partly used by me in WMO (2006). Subsequently an “end to end” flow scheme for agrometeorological information is discussed in an advanced way, using earlier approaches for a start (e.g. Stigter 2002a, 2004, 2007a, 2009b). Agrometeorology is then discussed from the point of view of applications and use, culminating into a thorough discussion of agrometeorological services in various sections. This Part I ends dealing with the boundary and initial conditions for solving problems with agrometeorological components in the livelihood of farmers using such services, directly and through public training involvement through intermediaries.

I.2 Agrometeorology, a Broad Definition (and Other Starting Issues)

I.2.1 Components of the Definition

Agricultural meteorology basically deals with water, heat, air and related biomass development, above and below ground, in the agricultural production environment. This is the physical environment of plants, trees, animals and any other organisms that are of importance for (or of influence on) food and fodder production and for production of any natural materials of which use is made in agricultural work and industry. This includes pests and diseases that also depend on these first mentioned factors, but it also includes the growing of biomass or use of discarded and waste biomass for energy purposes. For all three elements (water, heat and air) we may distinguish consequences and use but we will end up with another start of the definitions. However, the agricultural production environment has also social and economic components of which various aspects have to be considered in agrometeorology.

I.2.2 Water

As to water, this means mainly dealing with rain and all that happens to it after rain drop formation, including what occurs after it formed large quantities of moving water. We then have to do in agrometeorology with consequences and use of this water and the related water balances. Some examples of the consequences of water in the agricultural production environment are rainfall interception, evaporation, transpiration and the related cooling, leaching of soil nutrients, soil erosion, dew formation, flooding, forming a suitable environment for multiplication of certain plant diseases, spreading diseases by splashing. Its use is exemplified in water harvesting, irrigation, crop and animal growth, disease multiplication, keeping fish in rice fields and water use efficiency aspects.

However, two most serious facts about water are the increasing scarcity of fresh water for use in agricultural production for various reasons and the additional unequal distribution of water in time and space, which have got their place in this book. They spoil an enormous amount of development potential. Agrometeorology starts then suddenly no longer with a water related part of its definition but with the terrible availability and distribution conditions water shows under present living conditions (e.g. Irianto 2007), making it a subject of unprecedented resource wars (Klare 2006) as well as defense strategies in coastal and riparian areas.

I.2.3 Heat

As to heat, it mainly means radiation and what happens with it in the related balances. Examples of the consequences of radiation as a source of heat and of heat as a source of radiation are extreme temperatures (heating and cooling), drying of wet and porous water holding layers of biological and other materials, including top soils, heating of the same, and causing various types of drought in general. Light as a particular part of radiation causes photoperiodism and other biological phenomena. As radiation use we can mention photosynthesis, evaporative cooling as well as use in heating, including solar cooking, and drying. Both consequences and uses are complicated by the existence at all temperatures of balances in which also long wave radiation plays an important role.

A consequence of the combination of water scarcity and soil drying on a large scale is that it contributes to land degradation. Again agrometeorology does then not start with a heat related part of its definition but with the observation that accelerating desertification conditions, such as for example in northern China, should be combated (e.g. Zhaokui 2007) and that increasing global temperatures due to more atmospheric radiation absorption are seen as main causes of increasing climate variability and climate change (IPCC 2007).

I.2.4 Air

As to air, we have to consider the atmosphere and its movements. Wind engineering has defensive as well as consumptive aspects (e.g. Wisse and Stigter 2007). Some main consequences of air movement are wind related damage (by mechanical means, advected heat, drifting sand), particle and passive insect movements on various scales, and generally its acting as a carrier in many ways. While the use of air movement in the agricultural production environment is for example in the bringing of carbon dioxide, the bringing or taking away of heat and in drying but also in the use of wind energy in rural areas (Wisse and Stigter 2007).

But here again hurricanes and other damaging winds are major sources of destruction with serious social and economic consequences in poor and rich countries alike. Agrometeorology for a start has to do here with short and long term preparedness for actively diminishing damage and for adaptation strategies to living with unprecedented forces of air movement in agriculture, housing and industry.

I.2.5 Remaining Aspects

This still leaves us for the chosen definition with illustrating agrometeorology of soil, biomass and, as already initiated above, social and economic aspects of the production environment. How do they fit?

Soil is no agricultural meteorology, but consequences and use of water, heat, air, biomass over and in the soil are agricultural meteorology: e.g. several aspects of irrigation, soil water use by crops, mulching, underground storage, tillage, protection from wind and water erosion, stored water in the soil etc. In short, what happens with the elements at the interface of soil and air (and biomass and air, see below) is agrometeorology.

Biomass is no agricultural meteorology but consequences and use of water, radiation/heat and air in and around biomass are agricultural meteorology: e.g. phenology, sap flows, shade, growth, shelterbelts, frost protection, drying, intercropping aspects, live mulches, mulched horticulture or agriculture under simple covers and in glass houses, etc.

Society and economics are no agricultural meteorology but consequences and use of water, radiation/heat and air in society and economics, as far as the agricultural production environment is concerned, are agricultural meteorology: e.g. socio-economic aspects of irrigation, storage, agroforestry, floods, drought, desertification, frost, wind protection, artificial growth conditions, sustainable farming and related farmers' income etc., in short: socio-economic aspects (including cost/benefit ratios) of agrometeorological services, including preparedness for extreme events and environmental degradation, and their consequences for providers and users.

This section inherently shows that agrometeorology starts with the conditions in the livelihood of farmers and the most thorough possible needs assessments for problem solving with agrometeorological components (e.g. also Stigter 2008). In the above it should be realized that in the very interdisciplinary applied field of agrometeorology, depth of knowledge may often have to come from overlapping disciplines as soil science, plant science, animal science, climatology, phytopathology, aerobiology, hydrology and other agricultural engineering, in which also the basic sciences play an important role (WMO 2006).

I.3 Agrometeorology, an "End to End" Information Flow Scheme

I.3.1 Genesis of a Conceptual and Diagnostic Framework

Over the last decade there has been an increasing interest in stimulating the flow and use of scientific information in agricultural production in general and of weather and climate information in particular, especially in developing countries (e.g. Stigter et al. 2007a; Pulwarty et al. 2010). This should be a consideration of information from start to finish, from where it is generated to where it goes in decision making. However, the latter flow has been dominated too much by attempts to get too general climate forecast information applied (e.g. Pulwarty et al. 2010), with inappropriate needs assessments (Stigter et al. 2010) and ineffective means (Vogel and O'Brien 2006). See also Chap. IV.12.

Farmers' actions have consequences for sustainable development. This drives policy formulation with the aim to influence the behaviour of farmers and other resource managers in order to achieve better outcomes in terms of improved livelihood of people in rural areas (CAgM 2006). CAgM (2006) also acknowledged the conclusion from one of its Expert Teams, headed by Holger Meinke (see also Meinke et al. 2006), that both farmers and policy makers need to have access to relevant decision information, beyond that offered by general climate forecasts. So far, climate prediction science has, by default, driven the development of climate application tools. Experience over the last decade indicates the need for a user-oriented approach to applications development that is characterized by participatory approaches (e.g. Stigter 1999; CAgM 2006; Roncoli 2006).

When involved in an Asian Climate Training Workshop on "Climate Information Applications", at the Asian Disaster Preparedness Centre in Bangkok, I presented for the first time such an "end to end" flow scheme of agrometeorological and agroclimatological information (Stigter 2002a). By now Annex I.II as a conceptual and diagnostic framework is an accepted explanation, not only of information flows but also of the failures of these flows to reach farmers with limited formal education in developing countries (Stigter 2009a). Although open to much improvement, there are good examples of such successful flows in developed countries, in commercially developed services or in public services, but very few in developing countries, as for example illustrated for groundnut growing by Vijaya Kumar and Stigter (2010).

For the planning of programs for agrometeorological services, supporting the decisions and actions of producers, and related training and co-operation, it is important to recognize two basic challenges. These are: (i) understanding the ways in which agrometeorological support systems and agrometeorological services are related (mechanisms) and (ii) realizing the wide spectrum of problems encountered and decisions to be taken in agricultural production in relation to weather and climate for which such services should be developed. This can only be done by using available tools as operationally as possible (Stigter et al. 2010).

I.3.2 Details of the Information Flow Scheme

Annex I.II shows the "end to end" information flow scheme that schematically deals with these matters. The actual separation between agrometeorological services in the livelihood of farmers (A-domain) and the scientific support systems of data, research, education/training/extension and policies (C-domain) was illustrated by interposition of a so-called B-domain, to further increase the operational character of applied agrometeorology. The B-domain has three components in (1) improved (traditional indigenous) adaptation strategies based on farmer innovations, (2) functionally selected contemporary science and technology and (3) an understanding and assessment of prevailing policy environments.

These components may be supposed to form the operational building blocks of agrometeorological services. One of these components being incomplete will jeopardize the mechanisms of establishment of operational agrometeorological services (E2 in Annex I.II) that can make a difference in the A-domain. Going from the C-domain to the B-domain involves an upgrading of the operationability of the scientific support systems.

This upgrading is mostly driven by general agrometeorological action support systems for mitigating impacts of disasters (E1) and more occasionally by making use of the windows of opportunity that weather and climate offer. However, problem solving in the livelihood of farmers necessarily needs another increase in the operational use of knowledge, by applying the mixture of the B-domain into actual agrometeorological services supporting the decisions and actions of producers (E2). Of course in each of the three domains one makes use of data, research, education/training/extension and policies, but only in the C domain are they to be considered of a purely supportive nature. In the B and A domains and in E2 and E1 they are (or should be) used/carried out *in action* (Stigter 2009b).

This is an essential difference that so far is most often not recognized, because, following developed countries, where so many agrometeorologists are trained, we are everywhere too obsessed with methodologies and science as such. The closest *action* is most often in E1. These actions are the bulk of our good intentions to mitigate impacts of disasters and to use the four ingredients of the support systems in other applications in the real world. Unfortunately they have often still little to do with the needs of the A-domain, in which agrometeorological services should deliver support for farmers' decisions/actions.

E2 supporting actions are actual agrometeorological services that do relief constraints under the livelihood conditions of the local farmers. This means that needs assessments with respect to agrometeorological services for the farming systems concerned should come first. In the matrix of Annex I.II, vertically we have the three domains and horizontally we have the various farming systems. However, the pushing/guidance is from right to left (Stigter 2009b).

I.3.3 The Direction of Guidance

Is it possible to have the guidance/pushing from left to right (e.g. Stigter 2008)? This can first be exemplified from the change of relations between manufacturing industry (as an A-domain of applied sciences), where the support systems provide services in industrial innovation and production, and physics (as a C-domain of such support systems) in the 1950s/1960s of the former century. Quite some industry in the developed world was for a long time thriving on applications of results earlier obtained in theoretical and experimental physics.

However, when I studied experimental physics in Amsterdam in the 1950s and 1960s, physicists working in the industry, for example at the Philips Physics Laboratories, guided/pushed developments in experimental and related theoretical physics. Results in solid state physics were applied in electronics because the electronics developments had pushed the physics backing new applications. This was also reflected in our physics teaching.

This is exactly what now happens in Europe again, to remain competitive with the USA. Shannon (2007) reported recently on public-private partnerships to stimulate European research and bring it to market. This is in the fields of nanoelectronics and information (management) technologies. This is a reaction to the reproach that European research is often world-class but unresponsive to the real-world marketplace (Shannon 2007). In agricultural production such a partnership approach would solve the problem for the remaining farmers in industrialized countries. In developing countries for example provincial universities should focus on the problems of their regions and local governments should have partnerships with Universities, Research Institutes and Weather Services for the joint development of public services (Stigter 2002b).

An illustrative example from agricultural production of this change of direction in pushing/guidance may be taken from plant breeding. The green revolution was largely driven by scientific developments. These were important and led for example in certain parts of India to faster economic growth in the 1980s, but their limitations became also quickly clearer because of the too high input requirements (e.g. Sachs 2005) and lasting dependence of poor farmers on seed and input suppliers (e.g. Wahyuni 2007; Macan-Markar 2008). Presently, parts of breeding research are however driven by needs of poor people, aiming at for example disease or drought or lodging resistance and at increase of protein, vitamin and micronutrients contents of seed, with an emphasis on varieties suitable for mixed cropping (Mation 2003), a guidance from the A-domain towards the C-domain. In Low External Input Sustainable Agriculture (LEISA) approaches (e.g. Reijntjes et al. 1992; Baldy and Stigter 1997) research on pro-poor technologies under conditions of complementary institutions and policies to ensure broad adoption and benefit sharing (Mation 2003) has come closest in doing this.

This should become more and more the horizontal situation in Annex I.II for farming systems problems in agrometeorology as well (Stigter 2008). Among others the research of the winners of the INSAM contests on good examples of agrometeorological services (see also Part II of this book) illustrates that this is very well possible (INSAM 2005, 2007, 2008).

It demands research funding policies that favour this type of guidance from left to right and back through the B domain, but this asks for a change in mindset for most funding organizations operating in developing countries. Whether it are organizations as different as WOTRO (Scientific Research for the Tropics, Netherlands), EC (European Commission, Brussels, INCO/DEV), APN (Asian Pacific Network, Japan) and the like, their review boards do understand very little about the actual research needs to improve the livelihood of farmers and are not actually interested in such approaches. I described this in December 2005 in an evaluation I was involved in and I have brought this in a shortened version in Box I.1, but made the organization concerned unrecognizable. Local governments should take the lead after we have overcome the broken aid promises of the G-8 countries and other political organizations (Sachs 2007).

Box I.1 Tensions in Scientific Research for Development

1. Do you think that tensions exist in general (in research for development)?

From many years of experience (I conclude) that tensions do always exist between the two goals of promoting top scientific research and promoting development in the livelihood of farmers and urban settlers. Because there is a reasonably good idea of what the requirements are of top scientific research but there is a very deficient idea of what and how scientific research can contribute to development. Deeply inside, most scientists believe that science has little direct contributions to make to development of the people in non-industrialized countries (. . .).

2. If so, how do you deal with these tensions in your research?

In all modesty I feel that compared to most western scientists working in or with Universities and Institutes in less industrialized countries, the groups I co-ordinated in Africa are among those that, after many failures, have most rigorously been able to apply – in my case as an agrometeorologist – what may be considered top science in the agricultural environment of the livelihood of farmers, while serving their immediate interests.

My African colleagues, my African (and some Dutch) students and myself have learned that in the present stages of development, "bottom up" is the only direction that matters in the livelihood of people in such countries. Tackling urgent priority problems (with scientific components), as identified and articulated by farmers/urban settlers, in a participatory approach, comes first. Once that has been well done, the relief measures have to be jointly determined by those local people, government policy and decision makers and, where necessary and possible, scientists. Only then should scientists be able to determine the scientific components of those relief measures and see what kind of interdisciplinary science can contribute in which way to these proposed solutions, including the feasibility of these solutions and of the policies behind them.

The reality is almost always the other way around. Scientists have methods and clever scientific knowledge of basic features (in our case of the environment and agricultural production). They look around for conditions under which these methods and that knowledge can be applied, independent of any urgency shown by socio-economic analysis. What is needed is to develop scientific contributions to what should most urgently be solved in the view of local people (. . .). (I for example defended) in Iran – for an audience of about 70 agricultural scientists and practitioners, with whom I interacted as the only speaker in a course of three days – the provoking thesis for local agricultural research, that "If the results can in no way get to the farmers, the research should not have been done"! Then I illustrated what is possible!

But most of these results were also published (. . .), scattered over many subjects, because they were chosen along the "bottom up" approach (. . .). And also our students used remote sensing techniques and modelling to understand processes; be it much less frequently than seen on average, because physical ground truth quantification of phenomena is in the inhomogeneous (tropical) environments often a preferable thing to do (. . .).

3. Do you think they (the tensions) exist in the case of our research?

Given my answer to the first question, they must exist (. . .). I have experienced them heavily the few times that I have tried from Asia. The reasons are the same as earlier mentioned. Insufficient understanding by donors, but also by reviewers, of what scientists should contribute to development. And absence of the participatory "bottom up" approach and of a sufficiently deep involvement, of candidates, supervisors and reviewers, with the actual livelihoods of those whose problems should be tackled.

Wherever (. . .) these days I talk to local scientists, they much too often talk immediately about "Centres of Excellence", sophisticated methodologies they want to acquire, Geographic Information Systems they want to apply, but seldom about problems that have to be solved with their scientific knowledge. And it is not very different with my western colleagues involved. So, logically, the tensions heavily exist in your case almost everywhere as well.

4. And if so, how do our programmes and projects deal with this tension?

Only if the above indicated "states of mind" can be altered, is there hope that donors get from you what they got from our projects, with all their existing flaws and weaknesses admitted (. . .). An integration of social, economic and other gamma science with beta science, in "bottom up" defined participatory problem oriented projects, has appeared indispensable in the agricultural sciences for non-industrialized countries. This is "science for development" to get into the direction that we advocate (. . .).

Above I indicated that "what is needed, also in your research, is to develop scientific contributions to what needs most urgently to be solved in the view of local people". And we need to do that in such a way that we do not create institutions and conditions that can not be maintained when we withdraw, unless of course final answers were found to problems and the research does not need to be continued.

Because of the latter reality, already long ago I have made pleas for our permanent involvement with Universities and Institutes in third world countries and countries in transition, with limited but sustainable inputs along lines indicated above. Capacity building in education geared to local needs and conditions can occur in this context without being an imitation of what we do at home. Those getting educated this way learn to work under their future conditions and with a focus on solving local problems that urgently need attention. This may include periods in western countries to become familiar with methodologies, more extensive literature and interdisciplinary approaches. That is indeed "science for development". Any other approach is bringing what was developed for and under our conditions to situations for which they weren't developed and in which they can easily do more harm than good.

The Dutch Government (DGIS, Directorate General of International Cooperation), when headed by Jan Pronk (who later on also acted as a special UN envoy in Sudan) as a Minister, was exemplarious in its understanding, at least at and near the top of the Organization. This shows the importance of the policy environment. The DGIS funded research education and training project "Traditional Techniques of Microclimate Improvement (TTMI)" carried out at four African Universities with Wageningen University (and Research Centre (WUR)), the Netherlands, as a guiding resource University, between 1985 and 2001, was an example (Stigter et al. 1995; Mungai et al. 1996; Stigter et al. 1998). It carried out research in which such horizontal guidance was practised from within the livelihood of farmers (A-domain) towards development of quantitative methods and other scientific support in the C-domain that were particularly suitable for African conditions (e.g. Stigter and Ng'ang'a 2001). Application of its results was the first yardstick of success, publications the second. About the applications, we show them in Parts II and III of this book and discuss them also in Chap. IV.9. The numbers of scientific and other publications from the period 1988 till 2007 are in List I.1. One should note the great variety of publications that shows the involvement in many networks.

In unpublished work I have recently called this approach "the undercurrent of applied science", based on Heilbroner's (1986) qualification of such approaches in economical sciences at the beginning of the twentieth century. Connection with the above is in Box I.2.

Box I.2 The Undercurrent of Applied Science

In his famous bestseller of the early 1950s "The worldly philosophers", on the "economics of our daily bread", Robert Heilbroner distinguished mainstream economic sciences and the undercurrent of economics. After mainstream pioneers Adam Smith and David Ricardo there was a place for the utopists and finally for a realistic socialist as John Stuart Mill. However, after Karl Marx and at the time of Alfred Marshall, the complacency of the mainstream scientific world of economics at the beginning of the twentieth century, explains Heilbroner, was in fact a main intellectual tragedy.

The undercurrent had a much less optimistic and much more realistic view of the developments of the world economy as well as much more attention for the absence of social justice. Had the academicians of that time paid more attention to this undercurrent, perhaps the great calamities of the first half of the twentieth century could have been prevented. In the mainstream there was no preparedness for the radical social changes that earlier the utopists and then a new undercurrent of economics thought to be necessary. It teaches us that conservatives can not ignore such ideas, says Heilbroner, without serious consequences. This sounds very familiar.

One may wonder whether a hundred years later we should not try to learn from this in the present situation of our agricultural and wider environment. It is true that we have just witnessed the undercurrent of applied science regarding warnings for global warming and climate change becoming almost mainstream, but as to the preparedness for radical social changes there is hardly a beginning.

In agricultural meteorology, mainstream applied science is a balloon that now at least feeds through its outlet general agrometeorological action support systems for mitigating impacts of disasters. These support systems presently consist mainly of monitoring, mapping and zoning, early warnings, forecastings and predictions, focused quantitative analyses, general weather advisories, methodologies in use, including software developments and simulations, and analytic methodologies for which a problem is sought that they can help solve. These actions are the bulk of our good intentions to assist in mitigating impacts of disasters and to develop better defined support systems in other applications in the real world.

However, what the mainstream misses is in the undercurrent of applied agrometeorology: data, research, education/training/extension and policies, used/carried out *in action* as priorities in the undercurrent of applied agricultural meteorology. In such agrometeorological services, and the same applies in soil science, water management, forestry, combating environmental degradation, crop pests and diseases etc., there is a combination of three issues (see also Annex I.II). These are (i) use of well understood traditional knowledge and indigenous technologies (their values and limitations), (ii) the use of carefully selected contemporary science and (iii) the existence of appropriate policy environments.

Agrometeorological services must relief constraints under the livelihood conditions of the various categories of farmers. They must prepare these farmers for climate use as well as for climate change and its consequences of more and more severe extreme events. This means in general that in the undercurrent of applied science, better needs assessments with respect to services, for the farming systems concerned or for other suffering communities, should come first. Also strong competition for resources up till the resource wars we are experiencing worldwide come in here.

And this is where over time the highest problems have occurred. In the western world agriculture, presently almost only relatively well educated farmers are left. They are able to absorb new information that even more and more becomes available commercially. The situation in developing countries is very different. Only a minority of rich farmers may be compared to those in the western world, a majority of farmers are poor and have relatively little formal education. They also have least power.

Moreover, Chinese field research has shown that rural people are heterogeneous in their education, income, occupation and demands for information. This diversity has not been genuinely identified and their detailed priority information demands have not been properly revealed. Needs assessments in a participatory approach under such conditions is only just a beginning part of the undercurrent of applied science.

In the new Guide to Agricultural Meteorological Practices of the World Meteorological Organization, a last Chapter is on "Communicating agroclimatological information, including forecasts, for agricultural decisions" and identifies the necessities of how to handle such problems. On-farm action research will be the foundation of this approach.

Mainstream science of the environment would do much better than in economics in the previous century if it went beyond further development of the action support systems, by really helping solve the problems in action. The developments in Low External Input Sustainable Agriculture (LEISA) research of the last twenty years show what is possible if norms and values in science show a paradigm shift towards valuing the basic issues in the undercurrent: realistic assessments of the environment and considerations of the plights of poor people. Radical social and economic changes are needed in developed and developing countries in dealing with both.

List I.1 Publications of the TTMI-Project (in the period of 1988–2007, details on http://www.met.wau.nl, under Employees, Affiliated Staff, Prof. Dr. Kees Stigter, homepage)

I	Papers in "hard" journals	75
II	Invited or selected contributions to books/monographs/CD-ROMs etc. (sometimes reviewed and/or edited)	98
III	Papers in "soft" journals or non-reviewed parts of journals and books	9
IV	Contributions to international (working) documents	57
V	Conference/meeting papers not issued in books	15
VI	Papers to popularize one's own science or to inform the public or scientific community at large	7
VII	Lecture Notes	25
VIII	Contributions to International or Regional Newsletters or Bulletins	15
IX	Contributions to local Newsletters	16
X	Internal reports which may be used for quoting	75
XI	Internet activities and papers only made available on the internet	21
XII	Theses supervised	36

I.4 Agrometeorology, Applications and Use

I.4.1 The Basis for Part III of This Book

Agricultural education has to be made more practical and more rural realities oriented while agricultural extension courses should be tuned to serve the needs of the rural communities through dynamic interaction with rural societies (e.g. NAAS

2005). For WMO (2009) I proposed that, as in this book, in University post graduate syllabi for the first time basic and applied agrometeorology should be completely separated. In a small group we decided on the framework and titles of subjects and I proposed later on that applied agrometeorology should be considered to be what we have here exemplified in Annex I.I. Everywhere under the advanced part of the syllabi I made the link between the Basic and Applied Agrometeorology.

Under the first subject in Annex I.I "Strategic use of climate information" this is in dealing with certain material in applied agrometeorology, suitable for policies and education/training/extension in the livelihood of farmers. Material that can support agrometeorological services but is based on the role of agrometeorological science in (a) combating disasters, (b) selection processes of (changes in) land use and cropping patterns and (c) selection of actual preparedness strategies for dealing with climate as adopted in agricultural production. This also applies to the role of science in (d) more efficient use of agricultural inputs, (e) selection of (changes in) livestock management patterns, (f) development of microclimate modification patterns and (g) designs of (changes in) protection measures against extreme climate and its consequences.

Under the second subject in Annex I.I, "Coping with climate variability and climate change", basic and applied agrometeorology connect in dealing with certain other material in applied agrometeorology, suitable for policies and education/training/extension in the livelihood of farmers. Material that can support agrometeorological services but is based on the role of agrometeorological science in (i) improving the issuing, absorption and use of climate forecast information in agricultural production, (ii) the sustainable development and use of agro-ecosystems, (iii) the detection of and awareness on increasing climate variability and the elevating climate risk and (iv) (changes in) adaptation strategies to climate changes.

Under the third subject in Annex I.I, "Coping with extreme meteorological events", the link between basic and applied agrometeorology is in dealing with largely additional material in applied agrometeorology, suitable for policies and education/training/extension in the livelihood of farmers. Material that can support agrometeorological services but is based on the role of agrometeorological science in (A) problems and solutions in coping with extreme meteorological events in agricultural production and challenges remaining for the use of science to contribute to problem analyses and designing valuable solutions in this context. The same applies to the role of agrometeorological science in (B) designing and selecting efficient early warning strategies and in increasing their efficiencies.

Under the fourth subject in Annex I.I, "Tactical decision making based on weather information", this link between basic and applied agrometeorology is in dealing with again additional material in applied agrometeorology, suitable for policies and education/training/extension in the livelihood of farmers. Material that can support agrometeorological services but is based on the role of agrometeorological science in (I) problems and solutions in using of and coping with weather phenomena in need of tactical decision making and challenges remaining for the use of science to contribute to problem analyses and designing viable solutions in this context, where necessary/possible making use of short and medium range weather forecasting. This applies also to the role of agrometeorological science in (II) designing and selecting weather related tactical applications for agricultural management and in increasing their efficiencies.

Under the fifth subject in Annex I.I, "Developing risk management strategies", the link between basic and applied agrometeorology is in dealing with final largely additional material in applied agrometeorology suitable for policies and education/training/extension in the livelihood of farmers. Material that can support agrometeorological services but is based on the role of agrometeorological science in (α) defining, managing and coping with weather and climate related risks in agriculture, (β) developing scales and tools for weather and climate related risk quantifications, (γ) improving weather and climate related risk assessments in agricultural production, (δ) designing and communicating improvements in farm applications of risk information products and (ε) improving coping strategies with weather and climate related risks in agricultural production, including the improved use of insurance approaches.

This book wants to deal with applied agrometeorology and the use of agrometeorology in the above indicated way to fill some of the clearly existing gaps in systematic collection of such information. In Part III the above approach has been used towards the eight subjects that we had decided on in the building up of the book (Stigter 2006b). Those who thought up the guiding topics of the syllabi, meeting in New Delhi in March 2007, were aware that some overlap between syllabi can't be prevented. Because for example in the fifth subject we are looking from the particular angle and perspective of "risk" at issues we have been looking at from other corners as well. But that is what it was meant to be.

The relation between Annexes I.I and I.II is in using the wording of the three domains and their connections in the syllabi and this way they strongly influence the contents in Part III of the book. The authors have been asked to take the descriptions above very seriously. It means that the Part III contains material that should be useful for policy and extension matters in the livelihood of farmers in connection with agrometeorological services as illustrated in Part II.

I.4.2 Other Contents of Syllabi in "Applied Agrometeorology"

Annex I.I being partly the basis for the subjects of Part III, we should say here something on its other contents. As soon as we separated "Basic" and "Applied" agrometeorology, in the latter we also have to lay an educational basis on subjects that are normally taken for granted. For the strategic use of climate information, one must often start by giving a recent historical view for the regions concerned of the subjects chosen under this heading. Such historical information, with emphasis on the last two decades, is rarely sufficiently available. It is insufficiently realized that trends of and outlooks for strategic use of climate information are only distinguishable from such historical information.

There is need in agrometeorology for more books and papers on such subjects in addition to all the cases collected in the present book. In such works and in agrometeorology in general, there should be additional attention for the systematic and standardized data collection (and publishing!) on such matters as (i) disasters, (ii) (changes in) land use and cropping patterns, (iii) actual preparedness strategies adopted in agricultural production, (iv) agricultural inputs, their efficiencies and their relations to climate, (v) (changes in) livestock management patterns, (vi) (changes in) microclimate modification patterns and (vii) (changes in) protection measures against extreme climate, in line with Sect. I.4.1. This will assist a lot in policy design features and in designs of agrometeorological services in these issues under the strategic use of climate information. Understanding the role of science in working on these matters would be highly served by such systematic and standardized data collection.

A comparable story may be given with respect to coping with climate variability and climate change. For the subjects under that heading historical information, with emphasis on the last two decades, would be of equal importance, including trends and outlooks. This is shown by the proposed syllabi in Annex I.I. In addition to all the cases collected in this book, there is need for more papers and books in that direction as well. In such works and again in agrometeorology in general, systematic and standardized data collection should cover here (i) the issuing, absorption and use of climate forecast information in agricultural production, (ii) agro-ecosystems and (iii) (changes in) awareness on increasing climate variability and the elevating risk, again in line with Sect. I.4.1. This will also here assist a lot in policy design features and in designs of agrometeorological services in these issues under coping with climate variability and climate change. Understanding the role of science in working on these matters would again be highly served here by such systematic and standardized data collection.

For coping with extreme events and tactical decision making based on weather information, the proposed syllabi have taken the approach of case studies. This already implies a historical approach from which trends (action strategies) and outlooks (challenges remaining) could be derived. As in the previous two headings of Annex I.I, for these subjects again more books and papers would be very welcome and in such works systematic and standardized data collection would need priority. This would cover problems and solutions in coping with extreme meteorological events and with weather phenomena in need of tactical decision making as well as (changes in) early warning strategies and such tactical application for agricultural management. This is all still in line with Sect. I.4.1. What applied to policy design features and in designs of agrometeorological services for the earlier two subjects applies here again for the third and fourth heading of Annex I.I, while understanding the role of science in working on these matters would again be highly served by such systematic and standardized data collection as proposed.

For developing risk management strategies, the same approach with respect to historical information, trends and outlooks was chosen for the proposed syllabi. The systematic and standardized data collection applies here, in line with Sect. I.4.1 to (i) weather and climate related risks in agriculture, (ii) case studies of weather and climate related risk quantifications, (iii) weather and climate related risk assessments in agricultural production, (iv) case studies of farm applications of risk information products and (v) coping strategies with weather and climate related risks in agricultural production. The other aspects mentioned for the importance of such issues above equally apply to this fifth heading of Annex I.I.

I.5 Agrometeorological Services

I.5.1 Description of the Situation

Recently I concluded in one of my home pages for INSAM from the experience obtained that

- in most developing countries there does not exist a systematic review of farmers' needs for weather services and related information, region by region and farming system by farming system, including livestock, forestry and fisheries;
- this applies to a minority of richer producers that could be assisted by private sector initiatives and to the majority of poorer farmers etc. that would need public sector assistance, differentiated after their farming systems, levels of education and income;
- dialogues with farmers, pastoralists, forest dwellers and fishermen and their communities are the very beginning to get them interested in services regarding their preparedness for extreme climatic events and for making use of the benefits climate may offer;
- specially in-service trained extension intermediaries are needed between the weather products (maps, forecasts, warnings, response proposals) as well as design rules (advisories on mitigation of weather and climate impacts) and their rural potential clients, that are vulnerable and mostly have relatively low formal education;
- provincial or sub-regional agrometeorologists are an important asset but only when they get the means and backing to actually make a difference in the livelihood of farmers etc. and assist them to respond to variable weather and changing climate;
- last but not least, if we succeed in creating such weather services, consequences of climate change can be faced with much more confidence than presently is the case.

I translate this experience again as a confirmation of the needs for agrometeorological services that we already derived above from the scheme in Annex I.II. The connection with the climate change issue is of utmost importance here. This is nothing new as we will see below.

I.5.2 Some Basic Issues Exemplified

Agrometeorological services were most recently exemplified among others in Murthy and Stigter (2006), WMO (2006), Stigter (2007a, 2009a) and WMO (2010), while Part II of this book gives detailed examples using protocol forms developed for the INSAM contest of best examples of agrometeorological services and the preliminary results of a Chinese pilot project. The introduction of Part II explains their character further. Below we illustrate earlier distinguished categories of such services.

It can't be emphasized enough that for example mapping of disaster prone areas as an agroclimatological characterization product is not an agrometeorological service unless done in interaction with users. It only becomes an agrometeorological service when the final results have been introduced to users and are made use of by these users in interaction with the producers of the maps. Stigter and Al-Amin (2006) recently reviewed such preconditions and requirements for agrometeorological services in a checklist for action derived from discussing zoning and mapping in developing countries (Lists I.II and I.III).

What we arrived at there as preconditions, which are necessities without which no agrometeorological services can be established, and requirements, with their levels determining the quality of agrometeorological services, is equally valid for any other agrometeorological services and could have been derived from comparable reasonings and examples as we used from agroclimatological zoning and mapping.

As for example many examples in Part II show, advices on design rules on management or manipulation of above and below ground microclimate are no agrometeorological services unless users are participating in their preparations, designs and applications. This applies to any appreciable microclimate improvement in shading, wind protection, mulching, other surface modification, drying, storage, frost protection etc., with their wide definitions matching the wide definition of agricultural meteorology as given above (Stigter 1988b, 1994). These same derived preconditions and requirements summed up in Lists I.II and I.III, could easily have been derived from considerations of any of these improvements as agrometeorological service in practice, as Part II will illustrate.

With respect to the above subject we should recall that it also gave us the opportunity to bring the importance of traditional knowledge and indigenous technologies into agrometeorology, improved by physical understanding (Stigter 1982b). Prepared by an analysis of farmer oriented research needs in Tanzania (Stigter and Hyera 1979; Stigter 1982a), we reviewed traditional use as well as explanations of physical cause and effect relationships of mulching (Stigter 1984a, 1984b), shading (Stigter 1984c), wind protection (Stigter 1984d) and other related surface modifications (Stigter 1985), never omitting the social and cultural contexts (Stigter 1987, 1992). Reviews for the fields of agroforestry (Stigter 1988b) as well as microclimate management and manipulation (Stigter 1988a; Stigter et al. 1992; Stigter 1994) were followed by overall context reviews of the importance of traditional knowledge in agrometeorology (Baldy and Stigter 1997) and our own research (Stigter and Ng'ang'a 2001). It then got its solid place in Annex I.II since 2002 till the present (Stigter 2007a, 2009b, 2008; WMO 2010), while in the meantime generally accepted in agrometeorology (e.g. Motha and Murthy 2007).

Advices based on the outcome of response farming exercises, from sowing window to harvesting time, using recent climate variability data and statistics or simple on-line agrometeorological information from an operational group of agrometeorologists assigned this duty, become again agrometeorological services. But only so when obtained together with inputs and assessments from farmers or intermediaries between these products and the users. It is our experience that the organizational power of such operational groups and their communication with these intermediaries or direct users are the crucial factors in these matters and demand for financial as well as scientific backing, locally as well as internationally. Box I.3 gives the example of the Indonesian Climate Field Schools that illustrates this.

Box I.3 Climate Field Schools in Indonesia

I visited at the end of February 2007 organizers, trainers and farmers involved in organizing the unique "Climate Field Schools" (CFSs) in Indramayu, Indonesia, 250 km east of Jakarta. Farmer groups took already twice part in such field schools, which are based on the experiences obtained with "Farmer Field Schools" developed in Integrated Pest Management (IPM) extension. The latter gave Indonesia some international fame over the last decade and application of such schools in coping with climate disasters appears a very good idea.

The CFSs were formulated by BMG (Agency for Meteorology and Geophysics, the Indonesian National Meteorological and Hydrological Services (NMHS)), IPB (University of Agriculture, Bogor), the Directorate General of Food Crops (Jakarta) and the Asian Disaster Preparedness Center (ADPC, Bangkok). The main general aim of such CFSs is to increase farmers' knowledge on the application of climate information in their decision making. The organizers in Indonesia, the Directorate of Crop Protection within the Directorate General of Food Crops in the Ministry of Agriculture, just finished the most recent training of trainers in the CFSs in the week of 12–19 April 2007.

The most important climate information input is for the time being a forecasting of the start of the rainy season, as made by the BMG. The basic extension aim of the present CFSs is to get the farmers familiar with a better determination of appropriate rice planting times under conditions of a changing climate. The local farmers told me that given the changing variabilities, this was for them an absolute priority. The following phases of the crop do not pose them comparable problems unless there is flooding or drought.

The experiments in 2005 and 2006 have given rise to larger scale applications that will this year be carried out with more than 200 CFSs in 19 provinces. These earlier trials also convinced farmers that this approach was better than what they traditionally applied prior to 2005.

The role of the CFSs is that of the trainers involved being one class of intermediaries, between the forecasting products of BMG and the farmers, in an agrometeorological service act of joint determination of planting time. Farmers come with their own visual observations and next to BMGs' inputs there are those from one Automatic Weather Station (AWS) in Indramayu. The farmers act as field screeners.

Farmers being generally satisfied with the CFSs, the organizers and trainers see enough problems that have to be solved for improving the products at each level, that of BMG, that of training the trainers and that of advising the farmers. Firstly the BMG input information is general climate forecast information, not a product for the area or for farmers. Secondly, also planting time within the province is location specific and one AWS is insufficient. More ground truth, remote sensing and GIS applications could assist. Moreover, problems with the AWS and auxiliary equipment are rampant. Another type of intermediaries in the service of BMG should be able to look after such problems.

At the level of the trainers, the worries are mainly on sustainability of the present approach in the upscaling of CFSs and on reaching larger numbers of farmers that do not yet participate, without losing quality of information and feedback. New means of communication should be tried out, but cell phones are not yet suitable for a great majority of farmers. Rural radio would be a very fine medium but was not yet tried out.

At the level of the farmers, organized communications between intermediaries and trainees and among farmers after the CFSs must also be tackled in the future. Personal communications are at present the main form of contact between famers, comparable to what earlier Chinese research in poorer areas showed.

The next issue would then be what other problems with agrometeorological components could in the course of time get attention in the view of these rice farmers. My conversations showed that these have to be found in the direction of water management in floods and droughts, water use efficiency and crop diversifications, also using AWS and other data more effectively. This is confirmed by much of the later experiences in Gunungkidul (Winarto et al. 2008).

List I.II Summary of preconditions for development of agrometeorological services, in a checklist for action derived from discussing mapping and zoning as agrometeorological services in developing countries (Stigter and Al-Amin 2006)

- knowing poor farmers' needs the way they see them
- appropriate problem selection, together with decision makers for whom agrometeorological services have to be developed
- knowing regional details of the research questions encountered
- appropriate knowledge selection, to develop the required applied research focused on services
- best level trustable science

List I.III Summary of requirements for development of agrometeorological services, in a checklist for action derived from discussing mapping and zoning as agrometeorological services in developing countries (Stigter and Al-Amin 2006)

- liaisons with farmers, related NGOs and other related decision makers on what they did (traditional preparedness, coping and adaptation strategies), what they can do and what they want to do within the policy environment for agrometeorological services (disaster preparedness and mitigation; land use improvement)
- to determine appropriate policy environments for action on agrometeorological services, what can be done within the present policy environment (preparedness), and what policies may be necessary in the future for the agrometeorological services to be applied
- relevant basic policy decisions underlying the research requests
- best use of relevant basic operational research results obtained elsewhere
- best operational use of basic data
- appropriate basic quality education (in agrometeorology)

The agrometeorological pilot projects developed in Mali also remain a great example of response farming. This is about agrometeorological services in the form of useful on-line information for the ongoing season to assist farmers (i) in planning of operations (seedbed preparations, planting, thinning, weeding, spraying, drying, harvesting) within a proper time table and (ii) with rational use of their farmlands and inputs.

The absolute necessity here was the existence of two way telecommunication systems and a multidisciplinary team on hold that can formulate advisories from analysis of data and information received from (pilot) fields. Lists I.IV and I.V give a summary from the widely scattered piece by piece English and French (often grey) literature regarding the requirements of such projects and the results as they were obtained in Mali and elsewhere (Labine et al. 1991; Stigter 2006c).

Again, the preconditions and requirements of Lists I.II and I.III could have been derived from these requirements and these results in Lists I.IV and I.V as well.

List I.IV Requirements for carrying out the Mali agrometeorological pilot projects (Labine et al. 1991; Stigter 2006c)

- Crop (field) observations
- Soil (moisture) observations
- Routine meteorological observations

- Special meteorological observations (farm rainfall)
- Data management and data storage (bank)
- Provincial NMHS and an equivalent in Agronomy
- Agrometeorological Service (+ multidisciplinary team)
- Agrometeorological advisories and services
- Agrometeorological Bulletin/News
- Participation of National/Local radio/television
- Agrometeorological extension intermediaries

List I.V Results obtained in Mali and elsewhere in Africa with agrometeorological pilot projects (Labine et al. 1991; Stigter 2006c)

- Better understanding of response farming
- No necessity of re-seeding cereals
- More efficient determination of final plant densities
- More timely weeding
- More efficient spraying (cotton)
- More efficient use of fertilizers (where applicable)
- More efficient water use
- Inclusion of weather (rainy season) forecasts
- Higher yields (15 till 60% have been measured)
- Improved drought impact control
- Better locust (impact) control
- Better planning of agricultural development programs
- Use of local languages

I.5.3 Some More Examples

Establishing appropriate measures to reduce the impacts and to mitigate the consequences of weather and climate related natural disasters as agrometeorological services in agricultural production, can only be done when complying with farmers' conditions and needs using new weather and climate information approaches and technologies (Stigter et al. 2007a). See also Sect. III.2.1.(b). In well selected agrometeorological services for policy options for structural preparedness for and rehabilitation from disasters we must above all not forget about some basic difficulties generally encountered establishing services, as for example experienced after the big Asian tsunami (Stigter et al. 2007b).

Monitoring and early warning exercises directly connected to such already established measures as mentioned in the previous story are good examples of agrometeorological services. Rathore and Stigter (2007) discuss their assessment of agrometeorological risks. It is not always pertaining to early warnings on catastrophes. Das (2004) explained that one of the important parameters that can be measured with sufficient accuracy by remote sensing is the Sea Surface Temperature (SST), which has been related to the concentration of fish population. SST derived from

NOAA-AVHRR satellite monitoring serve as a very useful indicator of prevailing and changing environmental conditions. It is one of the important parameters indicating suitable environmental conditions for fish aggregation. It has been shown in India how SST can be mapped on a regular basis, passing it on as early warnings to fishermen, who could then concentrate on high potential areas and improve the catch. The influence of climate change is incorporated in the SSTs.

Climate predictions and forecasts and meteorological forecasts for agriculture and related activities, on a variety of time scales, from years to seasons and weeks, and from a variety of sources can become agrometeorological services. An illustrious example for the medium range is that of the Indian Agrometeorological Advisory Service (e.g. Rathore and Stigter 2007). But the necessity of incorporating farmer target groups appropriately is negatively illustrated by an example of drought forecasting from Brazil (Stigter 2004) and positively by that of the Climate Field Schools (CFSs) in Indonesia (Stigter 2007b; Box I.3).

In the first case, the drought forecasting "was appropriated and pressed into service of a policymaking apparatus designed to reduce the impacts of severe droughts". Policymakers started to exaggerate the potential usefulness of the science product, "therefore creating a situation of cultural dissonance between science and local knowledge and belief systems that quickly eroded the value of the information" (Lemnos et al. 2002). The government wanted to use the forecast to manage agriculture for the farmers, but the forecast appeared limited by the socio-economic conditions of the beneficiary population. Other agrometeorological services may be much more important under such conditions (Stigter 2004). See also Chap. IV.12, particularly Box IV.13.

The researchers in the course of time changed their focus from items around the start of the rainy season to studies of dry spells and pre-season weather/climate patterns. The authors conclude overall that in this case study, the limits of the use of climate information in policymaking derive in part form the levels of skill and direct usefulness of the science products themselves and in part form the necessity for a policy making apparatus to learn how to apply it usefully, in this case to drought mitigation (Lemnos et al. 2002). In general, climate prediction maximizes skill by reducing non-covariant random variability and for agricultural production it does so at the expense of relevance (Hansen et al. 2006).

In the positive example (see also Box I.3), the most important climate information input is a forecasting of the start of the rainy season. The basic extension aim of the present CFSs is to get the farmers familiar with a better determination of appropriate rice planting times under conditions of a changing climate. The role of the CFSs is that of the trainers involved being one class of intermediaries, between the forecasting products and the farmers, in an agrometeorological service act of joint determination of planting time. The need for a second class of intermediaries with the organizations that generate the climate forecast products became clear from this example as well (Stigter 2009b, 2007b).

Development and validation of adaptation strategies to increasing climate variability and climate change and other changing conditions in the physical, social and economic environments of the livelihood of farmers are good examples of agrometeorological services as we recently argued for diversification of rice based farming systems (Stigter et al. 2007a; Stigter 2007c). Part of the poverty-alleviation rationale for participatory rice research with agrometeorological components as agrometeorological service (Stigter et al. 2007a), appears to be that improved rice production – made possible by varieties that yield better, mature earlier, or tolerate drought (or, it may be added, by the new System of Rice Intensification, SRI) – will give farmers greater flexibility in their use of land and labor. This in turn will allow them to more easily diversify into higher value crops, without losing the food security provided by rice. Participatory research on rice also provides a practical entry point for building farmers' capacity to innovate and organize.

An interesting example contributed by agrometeorologists comes from Vietnam, encouraged by a workshop for provincial agrometeorologists in Hanoi in 2001 (Stigter et al. 2007b). After that workshop the government continued, as a form of preparedness for disasters due to increasing climate variability and climate change, as an agrometeorological service, to plan and design alternative cropping calendars and patterns, as well as water and tree management. Especially sowing times for the ongoing seasons in the Central highlands and the Mekong delta as well as some permanent changes in cropping patterns with two to three rice crops annually, in which one rice crop is replaced for a rotation with maize, sweet potatoes and cassava have been successful (Stigter et al. 2007a). See also Box III.2.2 of Sect. III.2.1.(b).

Another very recent example, from India, confirms earlier reports on available contingency plans of Indian state governments as adaptation strategies and as a service with agrometeorological components (Stigter et al. 2007b). There was an absence of monsoon rains of 20 days last summer (2005) in most areas of Chhattisgarh state. As soon as monsoon rains returned, farmers were advised to select their crop(s) among the short duration varieties of rice, red gram, green gram, black gram, soybean and groundnut for sowing. The extension officers of the state department of agriculture were in constant touch with (progressive) farmers to implement the advisories. The farmers in Raipur district of the state decided to sow rice for larger areas and soybean for the remaining areas. This all worked out fine. It may be noted here that the information had been delivered to the farmers well in advance, precise in space, coherent with available options and in a local language understandable to the farmers (Stigter et al. 2007a).

I.5.4 Some Special Elaborate Examples

A last case here comes from western China's Ningxia province as a farmers' innovation example (Liu Jing, private communication 2005/2006 in joint visits to Ningxia; Stigter 2006c). The area is about 200 km south of the capital Yinchuan, has 100–200 mm of rainfall annually and therefore suffers from drought and wind erosion. In an adaptation strategy, over large areas the surface is covered by farmers with artificial fertilizers, and then with about 10 cm of pebbles (collected with trucks from dry river beds). These pebbles prevent soil and fertilizers to be blown away by wind, warm the soil under abundant sunshine to a required temperature and make the water infiltrate into the soil with minimal evaporation losses from the surface (see also Sect. III.2.1.(f)).

They form this way a suitable seedbed for water melons that are sown through the pebbles into the soil using the available water and fertilizers. These water melons are sold with great profits in all major cities in China! This example shows that traditional farmer innovations when stimulated can be adapted to agrometeorological services that can be improved by supportive research as guidance from the A-domain towards the C-domain in Annex I.II. An update of this case, made in 2008, can be found in Sect. II.C.III.

The complexity of agrometeorological services in interaction with changing government policies is well illustrated by Box I.4 (most material taken from Zheng Dawei et al. 2005). This example from Inner Mongolia, China, also illustrates the better role that improved research can play in these areas.

Box I.4 Reversing Land Degradation from Wind Erosion

In China the ecological term of "ecotone" is used to indicate the region between full grazing and full cultivation in arable farming. Our foot hills region is such an ecotone with annual precipitation from 250 to 400 mm and topography of gentle hills, located to the north of Yinshan Mountain in Inner Mongolia. Since the middle of the nineteenth century, the ecotone consisted of grassland with interspersed cereal growing. Environmental degradation made the "ecotone" since the 1980s the poorest area of the whole of Inner Mongolia. Only in the 1990s did cultivated fields expand (close to 50%) and the numbers of animals double.

To combat this poverty situation, firstly water erosion on hills was overcome by replacing traditional slope planting into contour ploughing and planting. To combat the wind erosion, the deep ploughing or disc ploughing was replaced by conservation tillage. This way contour field construction takes only 30 man-days/ha. Subsequently a sowing machine was developed that add small quantities of irrigation water while sowing, eventually with added fertilizer. Quantities are determined after soil moisture and nutrient balances. These three key techniques combined with other techniques e.g. suitable crops and varieties selection, fertilizing the chestnut soil and plastic sheet cover, helped farmers greatly.

The Wuchuan Dryland Farming Experimental Station then developed an approach with a hill as a unit, in which in ecotone areas with sufficient rainfall the top of hills is used for no-grazing or low grazing grassland restoration. The lower slopes, less than 15°, are designated for contour fields with strip intercropping, and the valleys for pure strip intercropping, leaving stubble in the winter in alternating fields, with annual rotations. This was widely applied by farmers. After some years cropped fields are rotated with grassland for animal husbandry in controlled grazing, increasing restoring capacity from wind erosion. Cropping is intensified while more area is returned to grassland, compensating farmers with cereals and money in the form of cash. Advice is given to reduce the cropping/grassland ratio when the rainfall decreases from south to north in the ecotone area.

In the middle belt areas, with less rainfall, strip intercropping of grasses and crops could be allowed. Where rainfall is lower still, grass with shrubs under controlled grazing is promoted as a main undertaking, with only little intensive agriculture on flat land, like in earlier times. This demands from farmers in these areas even more change towards animal husbandry. The intense interaction between government and scientists at the County level and the growing role of the extension services due to new means and techniques of getting messages to the farmers have been spreading the advocated changes widely. This is particularly true for the villages in the southern areas of the foothills, with a higher income level and therefore more flexibility.

Particularly, much remains to be done in the areas of lower rainfall and dominance of grassland. Better quantification and techniques of wind erosion reduction may assist in adapting the government policies in such a way that also the small farmer may earn a living in regions where wind erosion has been successfully and sustainably reduced.

Specific weather forecasts for agriculture, including warnings for suitable conditions for pests and diseases and/or advises on countervailing measures, are of course very suitable for the design of agrometeorological services as well. An example from Ethiopia on using rainfall data to evaluate pest incidence, efficiency of fertilizers and efficiency of tillage was given by Tadesse (1994). He also reported that pastoralists are informed about grazing prospects and livestock conditions so that they can take proper action before any economic loss may be expected due to disastrous weather such as drought.

In the approach for the Asian Pacific Network (APN) project “Climate and crop disease risk management: an international initiative in the Asia-Pacific Region”, we already made use of the experience that agrometeorological services can be established with farmers from farmer participation and/or information products that are offered by meteorological services, research institutes and universities (institutions involved) (Stigter, 2006d). We can for such purposes distinguish the following five basic issues that have to be addressed in pilot projects:

1. Priority problem selection and determination of needs
2. Target group differentiation and fine tuning of problem definition and information needs assessment
3. Product selection, improvement and focusing (client friendliness)
4. Development and establishment of agrometeorological services (risk communications leading to preparedness and mitigations) from those products by applied scientists, government extension intermediaries and farmers
5. Upscaling from pilot projects through training exercises

This was applied in trying to get users involved in that project under the conditions that it should be realized that forecasts, predictions, models, decision analyses, communication methods (including participative research) are tools that only become (agrometeorological information) products when they can be operationally used by others down the line towards farmers for better preparedness and mitigation decisions (Stigter 2006d).

From this APN project proposal, application of the following explicitly wanted products can be read, on which the earlier defined farmer poverty level differentiation still has to be applied:

- predictive capacity in terms of climate, weather, disease and production capacity in combination
- model frameworks in farm and policy decision making
- management strategies/practices relating to pesticide usage to meet climatic circumstances and minimize crop losses

An interesting trend in Europe here, already longer occurring in the USA, is the commercialization of such services (Stigter 2006c). Crop management advices with respect to water (supplementary irrigation) and to plant diseases (minimum spraying), as agrometeorological services, have for example in the Netherlands been taken over by private enterprises. Field "scouts" make crop observations and report the presence of disease infection sources in the area. Automatic weather stations make measurements of air and soil microclimate, while weather forecasts can be integrated into the system. All network information is gathered by phone in a databank. Growers logging in receive all relevant data and recommendations for action for each field they want to manage: best time to spray, recommended fungicides, soil refill point and amounts of water. Results have for example led in the Netherlands to better water use efficiency, 800 farmers keeping potato blight under control, and 30% less sprayings since 1995. Such an approach has been exported (commercially) to Sweden (data collection), Poland and Japan (irrigation projects), South Africa (grapes/vines and tropical fruits) and Egypt (potatoes) (DACOM 2003).

Discussions on measures reducing the contributions of agricultural production to global warming can be found in Salinger et al. (1997) and Desjardins et al. (2007). They are also widely dealt with in the Chaps. IV.14–IV.16. Agrometeorological services to help reduce such contributions with additional benefits to production were reviewed for developing countries in Stigter et al. (2000). For these countries it is presently still indicated that mitigation techniques such as improved feed quality for a better digestibility, improved manure management, greater N use efficiency, better water management of rice paddies and/or increasing the role of agro-forestry in agriculture, have to be considered in order to minimize the impact of agriculture on climate (Vergé et al. 2007). See again also Chaps. IV.14–IV.16. In developing countries such as in Indonesia, it is an even larger problem to keep an optimum level of non-degraded land dedicated to agricultural production. Determining with agrometeorological factors, among others, high suitability of land use for agricultural purposes then becomes an essential issue (Stigter 2001, 2002c).

Proposing means of direct agrometeorological assistance to management of natural resources for development of sustainable farming systems, in technological advances with strong agrometeorological components, is the last example to be discussed here for agrometeorological services. The high value now everywhere given already for some time to agroforestry applications by poor farmers (e.g. Baldy and Stigter 1997; Stigter et al. 2002; Sachs 2005; Wisse and Stigter 2007) is a good example of valuing such agrotechnological advances, although it remains not without serious constraints under conditions of drought and land scarcity (Mungai et al. 2001; Onyewotu et al. 2003; Stigter et al. 2005a; Kinama et al. 2007).

Stigter et al. (2005b) have reviewed labour intensive traditional ways to cope with hail hazards. The recent serious hail damage in India made resurface the request for "high tech" intervention of cloud seeding as a service to farmers, with the argument that this was successfully done in Kansas, USA. However, Wieringa and Holleman (2006) have recently warned for the low chances of success because of differences between hail producing precipitation systems and the difficulties to appropriately prove successes of up to a maximum of 30% hail diminishment claimed in some places. Stigter advised in China the large scale labour intensive use of nets, as he saw them successfully applied in South Africa. An insurance approach is another management option.

I.5.5 An Approach We Do Not Need and What We Actually Want

In an editorial in "Science" in September 2005, Huntingford and Gash (2005) wanted to assist scientists in developing countries in a way I feel is disastrous. They stated among others that "technologies to run modeling experiments are now being made available to scientists in developing countries. But this initial technical capacity is of little use without the human scientific capacity to design and interpret the experiments. (. . .) There is strong argument for concentrating scientists at centers of excellence in the developing world. (. . .). This alarming forecast (50 million people will be at risk of hunger by 2050, and the majority of these will be in Africa) begs for an Africa-based research program to investigate the possible impacts of regional climate change".

In one of my items for the INSAM website (Stigter 2006e), also dealt with in one of my editorials there (the one used till June 2006), I replied among others: "Concentrating scientists at centres of excellence in the developing world is the last thing we need. Supporting scientists in existing institutions reaching out to those who need our help to survive the present hazards is what we need; at the same time preparing and facilitating policies that really would make a change in their livelihoods. An Africa-based research program to investigate the possible impacts of regional climate change will absolutely not contribute to the present lack of suitable policies that suit the poor in Africa; the same way as this would apply to China, India and Brazil. Thinking otherwise is really too naïve.

Ask our Chinese, Indian, Brazilian colleagues and those of ACMAD, Niger, who are already at such centres of excellence, what their main problems are. More funding, definitely, but that would solve institutional problems, not the problems with the distance between them and local, national, regional and international policy makers, nor the problems with their distance from poor people. Developing countries are involved in the international debates and negotiations and they need no empowerment on these fronts. They need policies of internal empowerment of the lower strata of their societies for such layers to be able to take part in the improvements occurring in the higher strata, at least in China, India and Brazil. In Africa the pertaining situation of clientelism looks even more desperate".

Sachs (2005) would find my last statement too negative and I am willing to go with him to support new generations of Africans locally as well. Science, and not only climate change science, has a role to play, but only when acknowledging the present livelihood situation of the poor and giving priority to policy preparations and policy mandate matters related to that situation; and to science only in that context (Sachs 2005; Stigter 2006a)!

As Annex I.I shows, much historical material needed for new policies would also be collected in writing these syllabi. For that part of these syllabi in which a link with basic agrometeorology is made (in the B-domain of Annex I.II), material has been collected in Part III of this book. It must show bedrock material for existing or new agrometeorological services. Within local agrometeorology, so on the scale of agricultural fields, this book wants to follow an approach in which actual problems in the livelihood of farmers are shown to be solvable using purely applied science, supported by the methods, as tools and approaches, of Part IV, that belong to the basic science (see Sachs 2005, for examples on a larger scale in the UN Millennium Project).

I.6 Boundary and Initial Conditions for Solving Problems with Agrometeorological Components

I.6.1 General Conditions

In Stigter (2006a) it has been argued with Mettrick (1993) that level and scale of basic and applied research and the use that is made of their results, obtained locally or elsewhere, greatly differ between countries. They particularly differ between industrialized and non-industrialized countries. In highly organized countries, direct contacts or various relatively well-organized channels exist, for example between farmers and those in agriculture related supportive industries and services, along which information is exchanged or at least can flow (e.g. Stigter 2005).

It was also argued there that public institutions, interest groups and private initiatives on a commercial basis stimulate this in "stronger" countries. Intentionally enabling public institutions and biased global markets make well-organized producers, which use available or new knowledge, survive in such countries (e.g. Stigter 2005). History shows that for example farming was able to cope with painful adaptations to changes, because of these institutions and conditions (e.g. Bonte-Friedheim and Sheridan 1997). The prices paid for safeguarded food security and food safety were permanent transformations of the agricultural professions, in which many farmers lost their means of existence, while the resource base is endangered in many ways in many places.

In developing countries (often seen as “soft states”) public institutions are seldom sufficiently helpful, rarely sufficiently organized and often not intentionally enabling its own officers or others to meaningfully support producers in decision making and in improving and protecting products and the resource base (Stigter 2006a); while markets are not conducive to production improvements (e.g. Abdulai and Hazell 1995; Sachs 2005). To a large extent only richer people are able to make use of whatever support systems are organized, while the majority of marginal people are left in misery (e.g. Jazairy et al. 1992; Sachs 2005; Stigter et al. 2005a).

Moreover, at best only very modest structures are in place that can deliver suitable information, or use existing information, to create appropriate services (e.g. Olufayo et al. 1998; NJAS 2004). Further environmental deterioration and alienating poverty are often a consequence of that absence of focused assistance (e.g. Galbraith as narrated in Parker 2005); because traditional knowledge and indigenous technology can often no longer cope with the dynamics of environmental and other changes (Reijntjes et al. 1992; Stigter et al. 2005b). An illustrative specific example from Sudan is given in Bakheit et al. (2001).

The above, as largely taken from Stigter (2006a), in fact details some important boundary and initial conditions for solving problems with agrometeorological components using agrometeorological services as well. It means that whether or not such absence of institutional conditions prevails, only new sustainable and renewable local initiatives may bring success (e.g. NAAS 2004, 2005). This may be exemplified with underground storage of sorghum in the Sudan (Bakheit and Stigter 2004) and again the CFSs in Indonesia (Stigter 2007b; Winarto et al. 2008; Box I.3), both confirming that resilience has a social as well as a technical dimension (ILEIA 2000; Holt-Gimenez 2001; Stigter et al. 2003; Winarto et al. 2008). In the first case, although farmer experiments existed and research improved the storage facilities as an agrometeorological service, this was insufficient for the spread of innovations (Bakheit and Stigter 2004). In the second cases, limited forecasting skill (Indramayu) and simple water management issues (Gunungkidul) met with farmers’ information needs and created working agrometeorological services conditions (Stigter 2007b; Winarto et al. 2008; Box I.3).

John Monteith (2000) in the first WMO/CAgM International Workshop preceding a CAgM session, in Accra in 1999, thought, with Austin Bourke in 1968, that as an initial and as a boundary condition of agrometeorological and agroclimatological sciences, there is ultimately a “strictly utilitarian path mapped out for us” (and Kees Stigter (1982a) expressed the same view already earlier). Salinger et al. (2000) referred in the same meeting to the need to meet ... “important aspects” ... “that have to do with macro-economic policies, gender aspects, agreements in global conventions and public policies” ... “that should be taken care of as other boundary conditions for projects”. Jagtap and Chan (2000) still in the same meeting gave examples of such factors as are limiting or enhancing production outside any recommendation domain of agrometeorology: resources (including soil types and their fertilities), economics, population dynamics (including ruminants), diets, policies (including planning), institutions, technical factors, educational factors, lack of baseline data, quantification methods in social sciences. These are initial and boundary conditions to be taken into account for solving problems with agrometeorological components.

I.6.2.a The Use of Intermediaries as Boundary Conditions

There is a large need for developing explicit education and training in the extension focused B- and A-domains for the various fields of agrometeorological services. This would indeed be a new approach if the results would be worked back as case studies into the education of the C-domain of Annex I.II, particularly in developing countries. The latter domain could that way become better focused on E1 and E2 undertakings and the necessary connection between E1 and E2 guidance, to enhance the operational qualities of agricultural meteorology, also in the educational exercises (e.g. Stigter 2003).

Such an approach would demand changes in the classical education and training in agrometeorology, making agrometeorological students and trainees much more aware of application needs and actual applications of services developed with the methodologies they learn so much about. It would also demand such changes when paying more attention to agrometeorology in other agricultural curricula and in any in-service training of agrometeorological personnel and agrometeorological intermediaries (e.g. Stigter 2003).

I.6.2.b Implications for Extension Agrometeorology

Education and training of intermediaries for agrometeorological extension has been proposed to be in two steps for two kinds of intermediaries (e.g. Stigter 2003). The first kind of agrometeorological extension intermediaries (AEIBs) would be close to the centers where the agrometeorological information useful for decision-makers in agricultural production is generated. They should basically be specially trained members of staff in the national weather services, at extension departments of universities and in research institutes.

Forecasts of weather and climate, monitoring and early warning products for drought, floods or other calamities, advisories for agrometeorological services that could increase the preparedness of the population long in advance, they have to be made into client friendly products that can be absorbed. This has to be done in the B-domain. For training such AEIBs they need a good education in farmers' needs as well as in how agrometeorology can be used in the A-domain, using information from the B-domain. They should themselves work in the B-domain, preparing E2 guidance.

The second kind of agrometeorological extension intermediaries (AEIAs) should be closest to the farmers and operate exclusively in the A-domain, using E2 guidance. They should learn to articulate the needs of the farmers' communities better and seek for agrometeorological components that need attention. They should match this with what is or should become available as E2 services, in strong contact with the AEIBs but not with the generators of the raw weather/climate products and raw advisories.

I.6.2.c Educational Consequences

In this two step intermediaries approach, meeting points for the two kinds of intermediaries have to be created in educational undertakings by the government or NGOs. The National Meteorological and Hydrometeorological Services (NMHSs) should with Universities and Research Institutes organize (the contacts with) the AEIBs. The existing extension services, the government or NGOs should organize the AEIAs and their contacts with the farmers. Enough research has been done for such approaches (e.g. Saleh 2007). A syllabus for such training should look as in Annex I.III.

The education and in service training of these two kinds of agrometeorological extension intermediaries is an essential part of the new approach that appears necessary in education, training and extension in agricultural meteorology. Their successes, failures and experiences will have to be brought back into the curricula of agrometeorological personnel of the NMHSs and into those at vocational schools and universities. To enlighten the classical C-domain training and strengthen its usefulness (e.g. Stigter 2003), because technological advance also requires effective education and policy making (e.g. Sachs 2006). As such the contents of this book should be accommodated in such an overhaul of the educational systems.

Annex I.I Postgraduate Syllabi Applied Agrometeorology

Proposed syllabus contents for postgraduate courses on "Strategic use of climate information", "Coping with climate variability and climate change", "Coping with Extreme Meteorological Events", "Tactical decision making based on weather information" and "Developing risk management strategies" in Syllabi of Applied Agrometeorology (see also WMO 2009). The contents will also be suitable for developing policies to support agrometeorological services.

Strategic Use of Climate Information

- **Increase awareness on potential climate hazards and mitigations**

  Elementary:
  History of climate related disasters (hazards and vulnerabilities) suffered in the continent/region/country/sub-region concerned and their documented or remembered impacts (with emphasis on last two decades); Efforts made in mitigating

impacts of (future) disasters (prevention); Trends discernable in occurrence and character of disasters, if any.

[Practicals possible on the last subject.]

Advanced:
Expectations on future disasters; Further efforts that could be made to mitigate impacts of disasters (prevent what can be prevented) and related policy developments; Systematic and standardized data collection on disasters and the role of science in combating them; Agrometeorological services to increase farmers' awareness on climate related disasters and potential mitigations.

[Practicals possible on the last two subjects.]

– **Selection of appropriate land use and cropping patterns**

Elementary:
History of main present land use and cropping patterns in the continent/region/country/sub-region concerned as related to environmental issues (including traditional techniques but with emphasis on last two decades); Successes and difficulties that farmers experience with present land use and cropping patterns; Outlooks for present land use and cropping patterns and possible alternatives from an environmental point of view; Recent trends in land use and cropping patterns.

[Practicals possible on the last subject.]

Advanced:
Outlooks for alternative land use and cropping patterns and what influences decision making on such alternatives; Policies to protect viable land use and cropping patterns and support appropriate alternatives; Systematic and standardized data collection on (changes in) land use and cropping patterns and the role of science in the selection processes; Agrometeorological services to increase farmers' design abilities of land use and cropping patterns.

[Practicals possible on the last two subjects.]

– **Adoption of preparedness strategies**

Elementary:
Priority settings for preparedness strategies in agricultural production; Preparedness for meteorological disasters in development planning; Permanent adaptation strategies that reduce the vulnerabilities to hazards; Preparedness as a coping strategy (with what cannot be prevented).

[Practicals possible on the last subject.]

Advanced:
Preparedness for reception of contingency responses; Preparedness as a community approach; Policies that enhance preparedness strategies; Systematic and

standardized data collection on actual preparedness strategies adopted in agricultural production and the role of science in their selection. Agrometeorological services to increase farmers' preparedness for climate disasters and their awareness of potential mitigations.

[Practicals possible on the last two subjects.]

– **More efficient use of agriculture inputs**

Elementary:
Agrometeorological aspects of agricultural production inputs and their history; Determination of input efficiencies; Other factors determining inputs and input efficiency; Actual use of inputs in main land use and cropping patterns of the region.

[Practicals possible on the last subject.]

Advanced:
Improvement of input efficiencies in agricultural production; Policies that enhance increased input efficiencies; Systematic and standardized data collection on agricultural inputs, their efficiencies and their relations to climate; The role of science in more efficient use of agricultural inputs; Agrometeorological services to increase farmers' abilities for more efficient use of inputs.

[Practicals possible on the last three subjects.]

– **Selection of livestock management**

Elementary:
History of livestock management patterns in the continent/region/country/subregion concerned as related to environmental issues (including traditional techniques but with emphasis on last two decades); Successes and difficulties that farmers experience with present livestock management strategies; Outlooks for present livestock management strategies and possible alternatives from an environmental point of view; Recent trends in livestock management strategies.

[Practicals possible on the last subject.]

Advanced:
Outlooks for alternatives in livestock management and what influences decision making on such alternatives; Policies to protect viable livestock management strategies and to support appropriate alternatives; Systematic and standardized data collection on (changes in) livestock management patterns and the role of science in selecting them; Agrometeorological services to increase farmers' design abilities of livestock management strategies.

[Practicals possible on the last two subjects.]

– **Adoption of microclimate modification techniques**

Elementary:
Microclimate management and manipulation methods (e.g. Stigter's review tables in Griffiths (1994)); History of microclimate modification techniques practised in the continent/country/sub-region concerned (including traditional techniques but with emphasis on last two decades); Possible improvements in adoption of microclimate modification techniques, given increasing climate variability and climate change; Local trends in adoption of such techniques.

[Practicals possible on the last subject.]

Advanced:
Outlooks for improved microclimate modification techniques; Policies to support introduction and extension of appropriate microclimate management and manipulation; Systematic and standardized data collection on (changes in) microclimate modification patterns and the role of science to develop them; Agrometeorological services to increase farmers' design abilities of appropriate microclimate modification patterns.

[Practicals possible on the last two subjects.]

– **Protection measures against extreme climate**

Elementary:
History of protection measures against extreme climate in the continent/region/ country/sub-region concerned (including traditional techniques but with emphasis on last two decades); Successes and difficulties that farmers experience with present protection measures; Outlooks for present protection measures and possible alternatives; Trends in protection methods against extreme climate.

[Practicals possible on the last subject.]

Advanced:
Outlooks for improved or alternative protection measures and what influences decision making on such alternatives; Policies to protect viable protection measures and to support appropriate alternatives; Systematic and standardized data collection on (changes in) protection measures against extreme climate and the role of science to design them; Agrometeorological services to increase farmers' design abilities of such protection measures.

[Practicals possible on the last two subjects.]

Coping with Climate Variability and Climate Change

– **Increase capacity in using climate forecast information**

Elementary:

History of the issuing of climate forecast information in the continent/region/country/sub-region concerned and its documented or remembered uses and impacts (with emphasis on last two decades); Factors determining the demand, release and use of climate forecasts for/in agricultural production.

[Practicals possible on following the present release and actual use of certain climate forecasts.]

Advanced:
Improvements needed in climate forecasting; improvements needed in issuing climate forecasts; improvements needed in absorption and use of climate forecasts, all in agricultural production. Systematic and standardized data collection on issuing, absorption and use of climate forecast information in agricultural production and the role of science in improving them; Agrometeorological services to increase farmers' awareness of climate forecast information, their absorption potential and their use of such information.

[Practicals possible on the last two subjects.]

- **Develop sustainable use of agro-ecosystem resources**

  Elementary:
  History of the use of agro-ecosystem resources in the continent/region/country/sub-region concerned and its documented or remembered sustainability or the lack of it (with emphasis on last two decades); Factors determining the sustainable development and use of agro-ecosystem resources.

  [Practicals possible on the actual use of such resources.]

  Advanced:
  Improvements needed in the sustainable development and use of agro-ecosystem resources; Policies to support such development and use; Systematic and standardized data collection on agro-ecosystems and the role of science in their sustainable development and use; Agrometeorological services related to farmers' sustainable use of agro-ecosystem resources.

  [Practicals possible on the last two subjects.]

- **Increase awareness on increasing climate variability and the elevating climate risk**

  Elementary:
  History of increasing climate variability in the continent/region/country/sub-region concerned and its documented or remembered elevated risk (with emphasis on last two decades); Factors determining the awareness on increasing climate variability and the elevating climate risk and examples of such increased awareness or the lack of it in agricultural production.

[Practicals possible on examples of increased awareness or the lack of it.]

Advanced:
Outlooks for improved awareness on increasing climate variability and the elevating climate risk and factors determining such improvements in agricultural production; Policies to increase such awareness; Systematic and standardized data collection on (changes in) awareness on increasing climate variability and the elevating climate risk and the role of science in detection of and awareness on such matters; Agrometeorological services related to an increase of farmers' awareness on the same.

[Practicals possible on the last two subjects.]

– **Increase understanding on adaptation strategies to climate changes**

Elementary:
History of adaptation strategies in agricultural production to climate changes in the continent/region/country/sub-region concerned (with emphasis on last two decades); the documented or remembered understanding of such strategies or the lack of it; Factors determining understanding on such adaptation strategies; Examples of increased understanding or the lack of it in agricultural production.

[Practicals possible on such examples.]

Advanced:
Outlooks for improved understanding on adaptation strategies to climate changes and factors determining the increase of such understanding in agricultural production; Policies to increase such understanding; Systematic and standardized data collection on (changes in) adaptation strategies to climate changes and their understanding and the role of science in such matters; Agrometeorological services related to an increase of farmers' understanding on such adaptation strategies.

[Practicals possible on the last two subjects.]

Coping with Extreme Meteorological Events

– **Develop understanding on the phenomena, impacts, actions, problems, solutions, policies, and remaining challenges based on case studies**

Elementary:
Description and characterization of selected extreme meteorological events and of impacts of these phenomena on agricultural production and infrastructure; Case studies to illustrate events and impacts suffered by farmers; Action strategies available to farmers to counter such impacts; Case studies of such action strategies and challenges remaining.

[Practicals possible on collection of local case studies.]

Advanced:
Case studies of problems encountered locally by farmers and solutions they developed in coping with extreme meteorological events; Case studies of such solutions developed elsewhere to such problems; The role of policies in promoting viable solutions to remaining problems; Scientific components of problems and solutions in coping with extreme meteorological events and challenges remaining for the use of science to contribute to problem analyses and designing viable solutions; Agrometeorological services to improve farmers' design abilities of solutions in coping with extreme meteorological events.

[Practicals possible on the last two subjects.]

– **Capacity to develop and implement effective early warning systems**

Elementary:
History of early warning systems for extreme meteorological events and their efficiencies in the continent/region/country/sub-region concerned (including traditional techniques but with emphasis on last two decades); Bringing such early warnings to users for discussions; Successes and difficulties that farmers experience with present early warning systems; Outlooks for present early warning system, their efficiencies and possible alternatives; Trends in early warning systems and their use.

[Practicals possible on the last subject.]

Advanced:
Outlooks for alternatives in early warning systems and what influences decision making on such alternatives; Policies to promote efficient early warning strategies and to support appropriate alternatives; Systematic and standardized data collection on (changes in) early warning strategies and the role of science in designing and selecting them and in increasing their efficiencies; Agrometeorological services to increase farmers' absorption of warnings and their actual use.

[Practicals possible on the last two subjects.]

Tactical Decision Making Based on Weather Information

– **Develop understanding of the weather phenomena, short and medium range weather forecast, impacts, actions, problems, solutions, policies, and remaining challenges based on case studies**

Elementary:
Description and characterization of selected weather phenomena and of impacts or use of these phenomena on/in agricultural production; History of short and medium range weather forecasting and their documented uses and impacts (with

emphasis on last two decades); Case studies to illustrate weather phenomena and tactical decision making to make use of or cope with these phenomena; Possible roles of improved short and medium range weather forecasting.

[Practicals possible on collection of local case studies.]

Advanced:
Action strategies available to farmers to improve the use of or coping with selected weather phenomena in need of tactical decision making, where necessary/possible making use of (improved) short and medium range weather forecasting; Local case studies of such action strategies or of such strategies developed elsewhere and challenges remaining. The role of policies in promoting viable solutions to remaining problems; Scientific components of problems and solutions in using of and coping with weather phenomena in need of tactical decision making, and challenges remaining for the use of science to contribute to problem analyses and to designing viable solutions, where necessary/possible making use of short and medium range weather forecasting; Agrometeorological services to improve farmers' design abilities of solutions in using of or coping with such weather phenomena.

[Practicals possible on the last two subjects.]

– **Capacity to develop tactical applications for agricultural management (e.g. pest and diseases, animal husbandry etc)**

Elementary:
History of selected weather related tactical applications for agricultural management and their efficiencies in the continent/region/country/sub-region concerned (including traditional techniques but with emphasis on last two decades); Bringing such tactical applications to users for discussions; Case studies of successes and difficulties that farmers experience with present weather related tactical applications; Outlooks for present tactical applications, their efficiencies and possible alternatives; Trends in such tactical applications and their use.

[Practicals possible on the last subject.]

Advanced:
Outlooks for alternatives for present weather related tactical applications for agricultural management and what influences decision making on such alternatives; Policies to promote efficient tactical applications and to support appropriate alternatives; Systematic and standardized data collection on (changes in) such tactical applications for agricultural management and the role of science in designing and selecting them and in increasing their efficiencies; Agrometeorological services to increase farmers' actual use of tactical applications in using of or coping with weather phenomena.

[Practicals possible on the last two subjects.]

Developing Risk Management Strategies

- **Risks in agriculture**

  Elementary:
  History of weather and climate as accepted risk factors in agriculture in the continent/region/country/sub-region concerned and the related documented risk concepts (including traditional concepts but with emphasis on last two decades); History and trends of defense strategies towards such risks in the same continent region/country/sub-region; Preparedness for weather and climate risks.

  [Practicals possible on the last subject.]

  Advanced:
  Who manages weather and climate related risks and who has to cope with weather and climate related risks in agriculture? Management strategies of and coping strategies with such risks, and trends in such strategies. Policies to enhance and improve such strategies. Systematic and standardized data collection on weather and climate related risks in agriculture and the role of science in defining, managing and coping with such risks; Agrometeorological services to increase design abilities of risk management strategies and of strategies to cope with risk.

  [Practicals possible on the last two subjects.]

- **Risk characterization**

  Elementary:
  Definitions and classifications of risks. Characterization of weather and climate related risks in agriculture. Water related risks. Radiation/heat related risks. Air and its movement related risks. Biomass related risks. Social and economic risk factors related to weather and climate.

  [Practicals possible on local recognition of the various risks.]

  Advanced:
  Quantification approaches of weather and climate related risks in agricultural systems; Successes and difficulties in using scales and other tools for weather and climate related risk quantifications; The role of science in developing such scales and tools; Policies to stimulate a quantitative and scientific approach of risk characterizations; Challenges remaining.

  [Practicals possible on applications of some scales and other tools.]

- **Approaches and tools to deal with risks**

  Elementary:
  History of methods for weather and climate related risk assessments in the continent/region/country/sub-region concerned and their documented evidence

of application to agricultural/farming systems. Strategies of dealing with risks: mitigating practices before occurrence; preparedness for the inevitable; contingency planning and responses; disaster risk mainstreaming.

[Practicals possible on local recognition of the latter strategies.]

Advanced:
Modelling risk assessments; Application of methods that permit the incorporation of weather and climate factors determining risks; Using short and medium range weather forecasting in risk assessment approaches; Using seasonal and long term climate forecasts in risk assessment approaches; Systematic and standardized data collection on weather and climate related risk assessments in agricultural production and the role of science in improving such assessments; Agrometeorological services to increase design abilities of risk assessments.

[Practicals possible on the last two subjects.]

– **Perspectives for farm applications**

Elementary:
Farm applications not yet dealt with, such as making risk information products more client friendly and transfer of risk information products to primary and secondary users of such information; Heterogeneity of rural people in education, income, occupation and information demands and consequences for risk information products and their transfer; Livelihood focused support, participation and community perspectives.

[Practicals possible on local recognition of the mentioned heterogeneity and its consequences.]

Advanced:
Case studies of farm applications of risk information products, including traditional technologies; Improvements needed in farm applications of such products and policies necessary to enhance improvements, including the use of intermediaries; The role of science in designing and communicating improvements in farm applications of risk information products; Agrometeorological services to increase farm absorption and use of risk information products.

[Practicals possible on the last two subjects.]

– **Challenges to coping strategies including transferring risks through insurance schemes**

Elementary:
Challenges to coping strategies: combining challenges to disaster risk mainstreaming, mitigation practices, contingency planning and responses, basic preparedness; Preparedness approaches reducing emergency relief necessities; The role that insurances can play in risk spreading and transfer.

[Practicals possible on the last two subjects.]

Advanced:
Implementations of challenges: adaptation strategies, relief responses, impact reductions, the many faces of preparedness; Policies to better meet the challenges; Systematic and standardized data collection on coping strategies with weather and climate related risks in agricultural production and the role of science in improving such coping strategies, including the improved use of insurance approaches; Agrometeorological services to increase design, absorption and use of such coping strategies.

[Practicals possible on the last two subjects.]

Annex I.II Conceptual and Diagnostic Framework: Information Flow

Conceptual and diagnostic framework as an "end to end" information flow scheme and to explain why special measures have to be taken to get the agrometeorological services through to farmers in developing countries.

A = Sustainable livelihood systems

B = Local adaptive strategies (knowledge pools based on traditional knowledge and indigenous technologies)
- **+ Contemporary knowledge pools (based on science and technology)**
- **+ Appropriate policy environments (based on social concerns and environmental considerations, scientifically supported and operating through the market where appropriate)**

C = Support systems to agrometeorological services: data + research + education/training/extension + policies

```
A ←-------|--------→  B   ←------|--------→ C
          |                      |
          |                      |
          E2                     E1
```

E1 = Agrometeorological Action Support Systems on Mitigating Impacts of Disasters

E2 = AgrometeorologicalServices Supporting Actions of Producers

Annex I.III Syllabi Agrometeorological Extension Intermediaries

Proposed agrometeorology related syllabi contents for in-service training of AEIA and AEIB intermediaries (see also WMO 2009).

– **an agrometeorology related syllabus for in-service training of AEIA intermediaries (extension agrometeorology within extension)**

  Elementary:
  Review of local administrational context issues: functions and responsibilities. Review of local climate issues, including traditional knowledge. Review of farming systems in the sub-region/country/region/continent concerned. Production constraints of farming systems reviewed. Fields of agrometeorology relevant to local agriculture (choice from INSAM categories for example). Agrometeorological components of production constraints identified. Assessments of needs as seen by the farmers in the various systems.

  [Practicals possible with farmers on the last two subjects and additional ones with AEIB intermediaries as indicated below. Results of such practicals could be discussed with AEIB intermediaries in joint classes.]

  Advanced:
  Review of processes of change (economical, social, environmental etc.) taking place in the sub-region/country/region/continent concerned. Extension approaches suitable in the farming systems reviewed for the production constraints identified. Policies of existing extension and their decentralization. Extension agrometeorology locally available to meet assessed needs. Agrometeorological services already applied or tried. New extension agrometeorology possible. Constraints in applying extension agrometeorology through agrometeorological services and their relief solutions.

  [Practicals possible with farmers on last three subjects and additional ones with AEIB intermediaries as indicated below. Results of such practicals should be discussed with AEIB intermediaries in joint classes.]

- **an agrometeorology related syllabus for in-service training of AEIB intermediaries (extension agrometeorology within NMHS, research institute, university)**

  Elementary:
  Needs assessments of farmers and farming systems for agrometeorological products. Available products from weather services, research institutes and universities directed at farming systems in the sub-region/country/region/continent concerned. Client friendliness of those products as assessed by users. Documented or remembered use of such products, successes & failures and assessment of their causes.

[Practicals possible together with the AEIA intermediaries on last two subjects. Results to be discussed in joint classes.]

Advanced:
Needs for additional products from weather services, research institutes and universities. How to commission such products in these organizations. How to make such products most client friendly for the farming systems concerned. Discussions on potential new products with potential users. Bringing new products into new or existing agrometeorological services.

[Practicals possible together with the AEIA intermediaries on last two subjects. Results to be discussed in joint classes.]

References

Abdulai A, Hazell P (1995) The role of agriculture in sustainable economic development in Africa. J Sust Agric 7:101–119

Bakheit NI, Stigter CJ (2004) Improved Matmuras: effective but underutilized. LEISA Mag 20(1):14

Bakheit NI, Stigter CJ, Abdalla AT (2001) Underground storage of sorghum as a banking alternative. LEISA Mag 17(1):13

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Bonte-Friedheim C, Sheridan K (eds) (1997) The globalization of science: the place of agricultural research. ISNAR, The Hague, 216pp

CAgM (2006) Report of Expert Team 3.2, Impact of climate change/variability on medium- to long-range predictions for agriculture under OPAG 3, Climate change/variability and natural disasters in agriculture. CAgM XIV/Doc. 11(2), WMO, New Delhi, 2pp

DACOM (2003) Crop management with plant-plus. Dacom Plant Service, Emmen (www.dacom.nl)

Das HP (2004) Satellite based agro-advisory service. In: Satellite remote sensing and GIS applications in agricultural meteorology, Report of a training workshop, Dehradun. AGM-8, WMO/TD 1182, WMO, Geneva, pp 347–359 [Also available on-line at the WMO/CAgM website]

Desjardins R, Sivakumar MVK, de Kimpe C (eds) (2007) The contribution of agriculture to the state of climate. Agric For Meteorol 142:87–324

Hansen JW, Challinor A, Ines A, Wheeler T, Moron V (2006) Translating climate forecasts into agricultural terms: advances and challenges. Clim Res 33:27–41

Heilbroner RL (1986) The worldly philosophers, 6th edn. Simon and Schuster, New York, 365pp

Holt-Gimenez E (2001) Measuring farmers' agroecological resistance to hurricane Mitch. LEISA Mag 17(1):18

Huntingford C, Gash J (2005) Climate equity for all. Editorial in Science of 16 September, 309:1789

ILEIA (2000) Communities combating desertification: livelihoods reborn. An Editorial. ILEIA Newsl 16(1):4–5

INSAM (2005) Results of the 2005 INSAM contest on the best examples of agrometeorological services. Available at www.agrometeorology.org under the topic "Accounts of Operational Agrometeorology"

INSAM (2007) Results of the 2006 INSAM contest on the best examples of agrometeorological services. Available at www.agrometeorology.org under the topic "Accounts of Operational Agrometeorology"

INSAM (2008) Results of the 2007 INSAM contest on the best examples of agrometeorological services. Available at www.agrometeorology.org under the topic "Accounts of Operational Agrometeorology"

IPCC (2007) Fourth assessment report. UN, New York, www.ipcc.ch

Irianto G (2007) Breaking the vicious cycle of water-related disasters. Jakarta Post, 22 March, p 6

Jagtap SS, Ah Kee Chan (2000) Agrometeorological aspects of agriculture in the sub-humid and humid zones of Africa and Asia. Agric For Meteorol 103:59–72

Jazairy I, Alamgir M, Panuccio T (1992) The state of world rural poverty. An inquiry into its causes and consequences. IFAD/New York University Press, New York, 514pp

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2007) Contour hedgerows and grass strips for erosion and runoff control in semi-arid Kenya. Arid Land Res Manag 21:1–19

Klare M (2006) The coming resource wars. On John Reid's statements. Energy Bull. (www.energybulletin.net)

KNMI (for Netherlands Government, compiled by Kees Stigter, second update, 2009) Capacity building in the area of agrometeorological services through roving seminars. Document originally distributed and presented as CAgM-XIV/INF. 4 at the XIVth Session of the WMO CAgM, New Delhi, October/November 2006, 19pp

Labine C, Stigter CJ, Vodouhe D (1991) Rapport de la mission d'evaluation du Projet BEN/87/010: Développement Agrometeorologique [Report of an evaluation mission of Project BEN/87/010: Agrometeorological Development.] UNDP/OMM, New York, 25pp and 7 Annexes

Lemnos MC, Finan TJ, Fox RW, Nelson DR, Tucker J (2002) The use of seasonal climate forecasting in policymaking: lessons from northeast Brazil. Clim Change 55:479–507

Macan-Markar M (2008) ASIA: Food crisis adds to women's burden. Inter Press Service (IPS) News Agency. April 29 http://ipsnews.net/news.asp?idnews=42162

Mation P (2003) The role of agriculture and rural development in eradicating hunger and poverty. Comments made at an ECOSCOC Roundtable. New York, 30 April, UN/ECOSOC, 10pp

Meinke H, Nelson R, Kokic P, Stone R, Selvaraju R, Baethgen W (2006) Actionable climate knowledge: from analysis to synthesis. Clim Res 33:101–110

Mettrick H (1993) Development oriented research in agriculture. ICRA, Wageningen, 291pp

Monteith JL (2000) Agricultural meteorology: evolution and application. Agric For Meteorol 103:5–9

Motha RP, Murthy VRK (2007) Agrometeorological services to cope with risks and uncertainties. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 435–462

Mungai DN, Stigter CJ (1995) The use of weather and climate information in planning and management of food security and production in Africa under conditions of increasing climate variability. J Afr Meteorol Soc 2:98–104

Mungai DN, Stigter CJ, Ng'ang'a JK, Coulson CL (1996) New approach in research education to solve problems of dryland farming in Africa. Arid Soil Res Rehabil 10:169–177

Mungai DN, Stigter CJ, Coulson CL, Ng'ang'a JK, Netondo GWS, Umaya GO (2001) Understanding yields in alley cropping maize (*Zea Mays L.*) and *Cassia siamea (L.)* under semi-arid conditions in Machakos, Eastern Kenya. J Environ Sci 13:291–298

Murthy VRK, Stigter CJ (2006) Operational agrometeorological services for extension needs and the supportive role of agricultural research. In: Strengthening operational agrometeorological services at the national level. Proceedings of a Regional Meeting, Manila, Philippines, 2004. AGM-9, WMO/TD-1277, Geneva, pp 199–208 [Also available on-line at the WMO/CAgM website]

NAAS (2004) Disaster management in agriculture. Policy paper 27, National Academy of Agricultural Sciences, New Delhi, 7pp

NAAS (2005) Redefining agricultural education and extension system in changed scenario. Policy paper 31, National Academy of Agricultural Sciences, New Delhi, 8pp

NJAS (2004) Diagnostic studies: a research phase in the convergence of sciences programme. NJAS-Wageningen J Life Sci 52:209–448

Olufayo AA, Stigter CJ, Baldy C (1998) On needs and deeds in agrometeorology in tropical Africa. Agric For Meteorol 92:227–240

Onyewotu L, Stigter K, Abdullahi Y, Ariyo J (2003) Shelterbelts and farmers' needs. LEISA Mag 19(4):28–29

Parker R (2005) John Kenneth Galbraith, his life, his politics, his economics. Farrar, Straus and Giroux, New York, 820pp

Pulwarty R, with contributions from Olanrewaju S, Zorba P (2010) Communicating agroclimatological information, including forecasts, for agricultural decisions. Chapter 17 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties in Asian regions. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 53–69

Reijntjes C, Haverkort B, Waters-Bayer A (1992) Farming for the future. An Introduction to Low-External-Input and Sustainable Agriculture. Macmillan, London; ILEIA, Leusden, 250pp

Roncoli C (2006) Ethnographic and participatory approaches to research on farmers' responses to climate predictions. Clim Res 33:81–99

Sachs J (2005) The end of poverty. Economic possibilities for our time. Allen Lane, London, 396pp

Sachs, JD (2006) Embracing science, technology to address global problems. Jakarta Post of 1 February, p 7

Sachs J (2007) The G-8's broken aid promises. Jakarta Post of 26 April, p 6

Saleh K (2007) Syaikhu Usman: urging civil society via research. Jakarta Post of 12 April, p 24

Salinger MJ, Desjardins R, Jones MB, Sivakumar MVK, Strommen ND, Veerasamy S, Wu Lianhai (1997) Climate variability, agriculture and forestry: an update. WMO 841, Technical Note 199, Geneva, 51pp

Salinger MJ, Stigter CJ, Das HP (2000) Agrometeorological adaptation strategies to increasing climate variability and climate change. Agric For Meteorol 103:167–184

Shannon V (2007) A "third way" on fostering research. International Herald Tribune of March 15, p 21

Stigter CJ (1982a) Environmental physics, agricultural research and development. Printed version of a public inaugural lecture in April 1980 upon nomination to Full Professor of Physics in July 1978. Inaugural Lecture Series, No. 30. Dar es Salaam University Press, Tanzania, 54pp

Stigter CJ (1982b) The use of physics in agricultural research. Int J Environ Stud 19:269–271

Stigter CJ (1984a) Examples of mulch use in microclimate management by traditional farmers in Tanzania. Agric Ecosyst Environ 11:173–176

Stigter CJ (1984b) Mulching as a traditional method of microclimate management. Arch Meteorol Geophys Bioclimatol B 35:147–154

Stigter CJ (1984c) Shading: a traditional method of microclimate manipulation. Neth J Agric Sci 32:81–86

Stigter CJ (1984d) Wind protection in traditional microclimate management and manipulation: examples from East Africa. In: Grace J (ed) The effects of shelter on the physiologyof plants and animals. Progress in Biometeorology Vol 2, Swetz and Zeitlinger, Lisse, pp 145–154

Stigter CJ (1985) Traditional microclimate management and manipulation in Tanzanian agriculture. A synopsis. Neth J Agric Sci 33:303–305

Stigter CJ (1987) Tapping into traditional knowledge. In: African revival. Rediscovering their own resources. (Centerpiece papers). CERES, FAO Rev 20(3):29–32

Stigter CJ (1988a) Microclimate management and manipulation in traditional farming. CAgM-Report Nr. 25, WMO/TD 228, Geneva, 20pp + 6 Appendices

Stigter CJ (1988b) Microclimate management and manipulation in agroforestry. In: Wiersum KF (ed) Viewpoints on agroforestry, 2nd Renewed ed. Agricultural University, Wageningen, pp 145–168

Stigter CJ (1992) Transfer of indigenous knowledge and protection of the agricultural environment: a project strategy in Eastern Africa with National Agricultural Research Institutes. In Warren DM, Slikkerveer LJ, Brokensha D (eds) The cultural dimension of development. Indigenous knowledge systems. Intermediate Technology Publ, London, pp 419–425

Stigter CJ (1994) Management and manipulation of microclimate. In: Griffiths JF (ed) Handbook of Agricultural Meteorology, Oxford University Press, Oxford, pp 273–284
Stigter CJ (1999) The future of agrometeorology: perspectives in science and services. WMO Bull 48:353–359
Stigter K (2001) Background of climate variability and climate change. In: Training workshop on agrometeorology, WMO/HMS/SNV, Hanoi, Vietnam, pp 276–281 [Proceedings in Vietnamese, an English text is available]
Stigter K (2002a) Opportunities to improve the use of climate forecasts. Asian Climate Training Workshop on "Climate Information Applications", Asian Disaster Preparedness Center (ADPC), Bangkok, Thailand, Bullet points + 18 pages, available on CD-ROM
Stigter K (2002b) Regional Universities need to focus on their regions. Opinion/Editorial. The Jakarta Post of 5 October, p 3
Stigter CJ (2002c) (i) Introduction to the Indonesian Conditions; (ii) Applying climate information for decision making in agricultural production and (iii) Adaptation options in agricultural production to climate related extreme events. In: UNSRAT (ed) Climate and Agricultural Production, Seminar in Agrometeorology, Faculty of Agriculture, Sam Ratulangi University, Manado, Indonesia, Lecture Notes, 43pp
Stigter CJ (2003) The future of education, training and extension in agricultural meteorology: a new approach. In: Zheng Dawei (ed) The future of education and training in agrometeorology in China. Proceedings of a Workshop, China Agricultural University, Beijing, pp 2–11 [All other papers in Chinese]
Stigter CJ (2004) The establishment of needs for climate forecasts and other agromet information for agriculture by local, national and regional decision-makers and users communities. In: Applications of climate forecasts for agriculture. Proceedings of the RA I (Africa) Expert Group Meeting in Banjul, the Gambia (December 2002). AGM-7/WCAC-1, WMO/TD 1223, Geneva, pp 73–86
Stigter K(CJ) (2005) Building stones of agrometeorological services: adaptation strategies based on farmer innovations, functionally selected contemporary science and understanding of prevailing policy environments. Opening Key Note Lecture at the FPEC Symposium, Fukuoka, Japan. J Agric Meteorol (Japan) 60:525–528
Stigter K (2006a) Scientific research in Africa in the 21st century, in need of a change of approach. Afr J Agric Res 1:4–8
Stigter K (2006b) A contemporary history of a new approach to applied agrometeorology. INSAM website www.agrometeorology.org under "History of Agrometeorology"
Stigter K (2006c) Agrometeorological services in various parts of the world, under conditions of a changing climate. Austin Bourke Memorial Lecture presented in the Royal Irish Academy, Dublin, in the evening of 2 March. Extended Abstract available on the INSAM website www.agrometeorology.org under "Accounts of Operational Agrometeorology"
Stigter CJ (2006d) Agrometeorological services in the context of climatic aspects of coping with crop disease risk. Paper presented at the Asian Pacific network scoping meeting of the project "climate and crop disease risk management: an international initiative in the Asia-Pacific region", 6–10 November, Hyderabad, India. Agromet Vision, Bruchem and Bondowoso, 5pp [Also available as PowerPoint presentation]
Stigter K (2006e) Equity climate for all. INSAM website www.agrometeorology.org under "Agromet Market Place"
Stigter CJ (2007a) From basic agrometeorological science to agrometeorological services and information for agricultural decision makers: a simple conceptual and diagnostic framework. A Guest Editorial. Agric For Meteorol 142:91–95
Stigter K (2007b) An account of visiting those involved in Climate Field Schools in Indonesia. INSAM website www.agrometeorology.org under "Accounts of operational agrometeorology"
Stigter K (2007c) New cropping systems to help farmers. Jakarta Post of January 22, p 7
Stigter CJ (2008) Agrometeorology from science to extension: assessment of needs and provision of services. Invited lecture at the 50th anniversary of the Chinese Academy of Agricultural Sciences, Beijing. Agric Ecosyst Environ 126:153–157

Stigter CJ (2009a) Scientific support to the establishment and validation of agrometeorological services. SciTopics. Research Summaries by Experts. Elsevier, http://www.scitopics.com/Scientific_support_to_the_establishment_and_validation_of_agrometeorological_services.html
Stigter CJ (2009b) Agricultural meteorology over the years and new priorities and consequences for curricula. Chapter 3 In: Guidelines for curricula in agricultural meteorology. Supplement No. 2 to "Guidelines for the education and training of personnel in meteorology and operational hydrology", Vol. 1, WMO 258, Geneva. www.wmo.int/pages/prog/etr/documents/258_vol1_Supp_2_1.pdf
Stigter CJ, Hyera TM (1979) Agrometeorological research needs in Tanzania. Agric Meteorol 20:375–380
Stigter CJ, Ng'ang'a JK (2001) Traditional Techniques of Microclimate Improvement African Network (TTMI/AN) project for research training. Successful research training partnership case study for GFAR-2000, Global Forum on Agricultural Research, Rome. Available on CD-ROM from FAO
Stigter CJ, Al-Amin NKN (2006) Zoning and mapping as agrometeorological services in developing countries: preconditions and requirements in a checklist for action. Paper presented at the COST/FAO/WMO/IBIMET workshop on climatic analysis and mapping for agriculture, bologna, June 2005. Available for example in: Stigter CJ, Agrometeorological services: theory and practice. University of the Free State, Bloemfontein, first paper in syllabus (February 2008)
Stigter CJ (coord & ed), Karing PH, Stigter CJ, Chen W, Wilken GC (1992) Application of microclimate management and manipulation techniques in low external input agriculture. CAgM Report 43, WMO/TD 499, Geneva, 192pp
Stigter CJ, Wang'ati, FJ, Ng'ang'a JK, Mungai DN (eds) (1995) The TTMI-project and the "Picnic"-model: an internal evaluation of approaches and results and of prospects for TTMI-Units. Wageningen Agricultural University, Wageningen, The Netherlands, 251pp
Stigter CJ, Van den Bor W, Daane JRV, Adam HS, Mohammed AE, Ng'ang'a JK, Mungai, DN (1998) The "picnic" model for research training at African Universities: evaluation and preliminary comparison. J Agric Educ Ext 5:23–38
Stigter CJ, Sivakumar MVK, Rijks DA (2000) Agrometeorology in the 21st century: workshop summary and recommendations on needs and perspectives. Agric For Meteorol 103:209–227
Stigter CJ, Mohammed AE, Al-Amin NKN, Onyewotu LOZ, Oteng'i SBB, Kainkwa RMR (2002) Agroforestry solutions to some African wind problems. J Wind Eng Ind Aerodyn 90: 1101–1114
Stigter CJ, Das HP, Murthy VRK (2003) Beyond climate forecasting of flood disasters. Invited Lecture on the Opening Day of the Fifth Regional Training Course on Flood Risk Management (FRM-5). Asian Disaster Preparedness Center (Bangkok) and China Research Center on Flood and Drought Disaster Reduction (Beijing), Beijing, September. Available from ADPC (Bangkok) on CD-ROM. Also available at http://www.agrometeorology.org/fileadmin/insam/repository/ADPC2mp.pdf
Stigter CJ, Oteng'i SBB, Oluwasemire KO, Al-Amin NKN, Kinama JM, Onyewotu LOZ (2005a) Recent answers to farmland degradation illustrated by case studies from African farming systems. Ann Arid Zone 44(3):255–276
Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005b) Using traditional methods and indigenous technologies for coping with climate variability. Clim Change 70:255–271
Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi YM (2007a) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 171–190
Stigter K, Das H, Nguyen Van Viet (2007b) On farm testing of designs of new cropping systems will serve Indonesian farmers. Available on the INSAM website under "Needs for agrometeorological solutions to farming problems"
Stigter K, Baier W, Barrie I, Brunini O, Dommermuth H, Gat Z, Gommes R, Keane T, Chan Ah Kee, Lomas J, Milford J, Ravelo A, Rijks D, Samui RP, Walker S, Wang Shili, Weiss A (2010)

General. Chapter 1 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Tadesse T (1994) Assessment of the contribution of meteorological information in assisting the economic development of Ethiopia. Conference on Economic and Social Benefits of Meteorological and Hydrological Services. WMO/TD 630, Geneva, pp 256–259

Vergé XPC, De Kimpe C, Desjardins RL (2007) Agricultural production, greenhouse gas emissions and mitigation potential. Agric For Meteorol 142:255–269

Vijaya Kumar P, Stigter CJ (2010) Agrometeorology and groundnut production. Chapter 10B In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www. agrometeorology.org) websites.]

Vogel C, O'Brien K (2006) Who can eat information? Examining the effectiveness of seasonal climate forecasts and regional climate-risk management strategies. Clim Res 33:111–122

Wahyuni S (2007) Rice culture week aims to promote farmers' sovereignty. The Jakarta Post of 4 April, p 8

Wieinga J, Holleman I (2006) If cannons cannot fight hail, what else? Meteorol Zeitschr 15(3):659–669

Winarto YT, Stigter K, Anantasari E, Hidayah SN (2008) Climate Field Schools in Indonesia: coping with climate change and beyond. LEISA Mag 24(4):16–18

Wisse JA, Stigter K (2007) Wind engineering in Africa. J Wind Eng Ind Aerodyn 95:908–927

WMO (2006) Commission for Agricultural Meteorology (CAgM). The first fifty years. WMO 999, Geneva, 44pp

WMO (2009) Guidelines for curricula in agricultural meteorology. Supplement No. 2 to "Guidelines for the education and training of personnel in meteorology and operational hydrology", Vol. 1, WMO 258, Geneva www.wmo.int/pages/prog/etr/documents/258_vol1_Supp_2_1.pdf

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by C.J. Stigter. WMO, Geneva, in print

Zhaokui F (2007) Environmental woes could sink China. Reproduced from China Daily in the Jakarta Post, 22 March, p 15

Zheng Dawei, Zhao Ju, Tuo Debao, Stigter K (2005) Reversing land degradation from wind erosion in Inner Mongolia: the choice between grass and bush restoration or conservation tillage of contour strip plantings depends on hill slopes and rainfall. J Agric Meteorol (Jpn) 60:337–341

II.A Introduction to Part II (INSAM Examples)

Kees Stigter

Of the examples of agrometeorological services for developing countries, distinguished under ten headings as recently reviewed (e.g. Stigter 2008c; WMO 2010), almost all products developed with focused scientific support are just the seeds sown for the development of actual agrometeorological services in an extension approach (Stigter 2009). But we want to get to a situation in which, in a "farmer first paradigm" (e.g. Chambers et al. 1989; Winarto 2007), livelihood problems and farmer decision-making needs can guide the bottom-up design of actual services. Services based on products generated by operational support systems in which understanding of farmer livelihood conditions and innovations have been used (Stigter 2008a). We have developed in the last decade a good idea of what is needed to develop such agrometeorological services from scientific products generated by National Meteorological and Hydrological Services (NMHSs), Research Institutes and Universities (KNMI 2009). But what we need is institutionalization of science supported establishment and validation of such services (Stigter 2009).

Of the examples originally collected in the INSAM contest for the best examples of such services (INSAM 2005, 2007, 2008), some have been institutionalized and some were developed with and for specific target groups of farmers but not institutionalized. These operational services are the best illustrations of what has been institutionalized in some countries and of what is needed to validate those examples and learn from them. While other examples show the missing links with the livelihood of larger groups of farmers (WMO 2010). The writing on these services was done using a procedure developed and accepted for this particular situation (protocol). The contents of these protocols were fully re-edited and updated for this book (List II.1). Below we make intercomparisons and draw lessons on focused supportive research, institutionalization and validation issues, also referring to other parts of this book. The ten categories of agrometeorological services earlier distinguished by Stigter (e.g. 2008c; WMO 2010) are in List II.2.

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_2,

In the first protocol of this Part II, on *Design of Sand Settlement of Wind Blown Sand Using Local Trees and Grasses (Sudan)*, one of a large number of services that we developed at Universities in Africa, it follows from our reporting that we indeed remained in the stage of focused scientific support. The category of agrometeorological services to which it belongs is D., the disasters being desertification and wind blown sand. But, as many examples will show, there are often double category services, because here the mode of the combating of disaster as an agrometeorological service belongs also to category B.

This is definitely unique research, an approach that can be of use everywhere in the world where sand encroachment by wind is a serious problem. The quantitative strategy developed in this problem solving is exemplarious and useful data have been obtained under extremely difficult field conditions. But without a serious follow-up by an internationally supported national institute or a specialized international institute on combating desertification, where the possibilities of air seeding at the right moments of the appropriate vegetation is seriously studied, there are no chances that the developments we report on can lead to any actual agrometeorological service as explained above.

We would like to prevent that we get in the same situation as explained under S. of this protocol, where we state that "The kind of design work on holding back the desert, reported here as an agrometeorological service, could also have been carried out on desertification issues that are at the basis of the resource wars that sparked off many of the civil war situations that occurred and are occurring in Sudan. Appropriate international funding of such work should have started in the 1960s and 1970s, 30–40 years ago, but was refused even 10 years ago for example by ISNAR". ISNAR is the Institute for Studies of National Agricultural Research of the Consultative Group of International Agricultural Research (CGIAR). But poor countries with regimes internationally seen as doubtful, definitely when acting towards the people suffering from the resource problems concerned, are now unlikely partners in the development of appropriate policies to carry out the required research and experiments. But very often national research institutes in Africa can be trustable partners that can do a lot without government interference.

We have shown here that with great efforts but relatively little means, field research of high quality could be carried out, in a research education context, that showed the direction in which further progress has to be made. The institutionalization of further research related to such problems looks very far away, the marginalization of people and countries suffering from such problems is most likely to remain. So far we have only sown the seeds for the development of actual agrometeorological services in an extension approach. Emergence of those seeds demands a very different international research environment and a very different international political support environment. Most chances for any future progress nationally we see in China.

The second protocol reproduced here, on an *Agrometeorological Service for Irrigation Advice (Cuba)*, is a typical example of a well institutionalized agrometeorological service, for the time being on the scale on which it was developed. It is also an interesting case of an issue we will come across again also several times below, that is the higher importance of water management improvement and of a gain in water use efficiency of crop growth, compared to low yield increases. Other examples of the same come form places as far apart as China and Sudan. The category of agrometeorological services to which it belongs is again D., the disaster now being drought. But this is again at least a double category agrometeorological service, because now the mode of combating disaster, as an agrometeorological service, belongs also to category J., water being the natural resource concerned (WMO 2010). However, expanding the definition of response farming as we recently did (Stigter 2008d), this may as well be considered an example of category C. (WMO 2010).

If we look at the difficulties experienced, some (such as the lack of agronomic data) are beyond the influence of those that developed the agrometeorological service. But these are issues that can not be described often enough, because they are much more general problems in most developing countries. They very often also prevent good validation attempts on a larger scale. However, other problems met, such as the "synchronization" of relevant radio broadcasts with the working hours of farmers, have also been reported to me from places as far apart as Indonesia and Nigeria. These are solvable problems when brought to light appropriately. And so are poor communications between users and service technicians as intermediaries. This is improving almost everywhere as long as we do not make the socioeconomically wrong choices of technology (Nicholson 2009). It is interesting to also note here the remark on the necessity of a minimum of such field technician intermediaries.

With increasing availability of these useful services as a main goal, this is an issue of successful institutionalization that we will come across several times in the protocols. It is clear that more than most Research Institutes and Universities, NMHSs these days aim more and more at institutionalization of the establishment of participatory services with farmers. The Mali agrometeorological pilot projects are among the best examples (see Part I and Stigter 2009). That is obviously because the word "Service" is in the name of these Institutions. But the development of "Services" Departments in Research Institutes and Universities would create a very important learning environment for those who want to bring science into the actual service to farmers (Stigter 2008b).

The third protocol, *Frost Forecast Service for Inner Mongolia in 2007 (China)*, is an example of the same kind. It belongs to agrometeorological services of the category H. but has components of E., while the defense measures we will discuss below belong to category D. However, expanding the definition of response farming as we recently did (Stigter 2008d), this may again as well be considered an example of category C (WMO 2010).

This is definitely an attempt at an institutionalized agrometeorological service, apparently applied on a larger scale in China, because the central China Meteorological Administration (CMA) asked the Provincial ones to collaborate in these developments. I was involved earlier in a frost forecasting publication in Iran (Rahimi et al. 2007). But that was a completely different approach. Not a period in which the frost could occur for the ongoing season but a general probability of occurrence was made available. The discussion here would again be whether farmers are really helped in the best way with such probability forecasts. Another advantage in the Chinese case is the concomitant advice on defense measures in case the crop cannot yet be harvested.

We wrote (Rahimi et al. 2007): “Bringing risk analysis of the last and first occurrences of frost and of frost-free periods to farmers in a way understood and appreciated by them is a very useful procedure to decrease frost hazards in farm management. It is believed that information on frost, provided along with information on the properties of climate, soil, and water, can help farmers to manage their agricultural activities much better. This can be considered an agrometeorological service to such farmers (e.g. Stigter 2005). A probability of occurrence of 75%, with a return period of 4 years, is a degree of risk that is accepted as an important yardstick when planning agricultural activities in Iran”.

What would be needed is of course in both cases a validation with independent data, to see how good the forecasts were and how they were used. Such validations are seldom built into the trials of such services. If built in, results are seldom made public. In both cases one would have to ask farmers for feedback. But in the Chinese case it is clearly indicated that the forecast is not given directly to farmers but reaches them through mass media as radio, TV, newspapers. In Iran the means of communication remained unclear. In both cases, using Climate Field Schools as such a meeting place of forecasters, or extension people trained by forecasters, and farmers would be a very good way of communicating the forecasts and obtaining feedbacks, also from more remote places.

The fourth protocol, *Design of Protection of Sloping Land from Soil Loss and Water Run Off Using Hedgerow Intercropping (Kenya)* gives the results of a project in which we had chosen for collaboration with an International Research Institute from the CGIAR. This was at the time the International Centre for Research in Agro Forestry (ICRAF). It is basically of the category D. (here with soil loss and water runoff as the disasters), again with the measures belonging to B., like in the first protocol above. One may also consider this work of the category J., with sloping land and water as the natural resources. It was “follow up” research of work we had done on alley cropping on flat lands (protocol number 9) at experimental fields outside the ICRAF fences. This was in the context of the National Dryland Agroforestry Research Programme (NDARP), because at that time (mid eighties) ICRAF was only a demonstration site, that was not allowed to do research on its premises! While they had done earlier work on sloping lands with a younger tree system and with the use of fertilizers. We both were therefore interested in what an aging tree system could do without the use of additional fertilizers on these sloping lands. A big advantage for us was that we knew that any results worth mentioning would go into the ICRAF extension system.

The most important farmers related issue in this work is the high efficiency of mulches in diminishing water run off. The hedges still also were very important in reducing soil loss, so they can’t be missed, their strong competition for resources not withstanding. What we learned was the importance of reducing the trade-offs between crop productivity and erosion control on sloping land in the semi-arid tropics. It appeared to be crucial to select hedgerows and to design hedge and tree spacings that minimize competition and provide adequate erosion control.

Although it was confirmed that it is difficult to increase LEISA crop yields in the semi-arid tropics with alley cropping on sloping land, it was also observed that strong remaining trade-offs need not be a major deterrent to adoption by farmers, in case grass and trees provide other direct and significant benefits to farmers. However, also the conclusions of Casey (2004) on adoption of agroforestry systems apply (see Box III.5.8 in Sect. III.5.2.(i)). It was concluded there that quite some agroforestry can be presented as a sustainable alternative to current methods of production in the tropics. If it is to succeed, the accompanying investments in the human capital of farmers through extension programs and on-farm training must be a part of the overall implementation strategy for agroforestry practitioners.

The fifth protocol, *Design of Multiple Shelterbelts to Protect Crops from Hot Dry Air (Nigeria)*, shows particularly the devastating practices of a government (in this case Forestry) Department to implement designs that were not based on thorough understanding of the micrometeorology involved and without involving local farmers. We must agree that it took us also quite some time before we understood that protection from hot dry air was what we observed in the quiet zone leeward of the belts. Only when the results of soil moisture data prior to sowing became available, we saw patterns explainable from decreased soil evaporation due to the protection of the soil from these same winds. The paper explaining this was refused by an agroforestry journal, because they did not believe us, but the same was accepted by a climatological journal. The category of services it belongs to is again D., with the disaster being the hot dry air blown by wind and the measures belonging again to category B., but one may also consider it an example of the G. category, the change being the desertification that occurred.

Another very important issue is the overwhelming influence on our understanding from the work done by a supportive M.Sc.-student on the socioeconomic aspects of the belts. The misconceptions due to this initial negligence were originally transferred to our team as well. Only after these socioeconomic surveys could we understand the situation in which the farmers were kept. It should be understood that the original designs were good enough to reclaim the area from desertification and to have protective grasses return. Only the crop protection from hot dry air was limited to about 5 and 6 times the height of the belts leewards and between 2 and 3 times windwards. Had they been perpendicular to the wind during the growing season, a distance of 10 times the belt height would have been sufficient for overall protection. But actual distances were between 15 and 25 times that height.

A final issue of importance here is the work done by another supportive M.Sc.-candidate on comparing traditional and scientific determination of planting dates. We have dealt with that issue in Box IV.4 of Chap. IV.4. We conclude there that, ideally, an agrometeorological advisory body should be formed by the government or NGOs that would be responsible, in a participatory approach with farmers and trained intermediaries, for predicting the onset dates "on line". That would be a highly needed institutionalization of this other service. This could guide decision making on (preparation of) sowing and on the safest types/varieties of crops to be selected. Again the Mali agrometeorological pilot projects are an example of this approach (Part I and Stigter 2009).

The sixth protocol, *Seasonal Vegetable Growing on Riverbeds – a Farmer innovation (India)*, is a straight example of category B. An approach where we originally aimed at also in our African research: to quantify traditional techniques of microclimate manipulation for a better understanding and for possible transfer to other places, eventually in a modified form. Our work on mulching, shading, wind protection and other surface modification as well as on drying, storage and related pests and diseases, as largely dealt with in Part I but also exemplified in Parts III and IV, was of that same kind. Eventual support to improvements would be of the category J.

The sowing places are low sand dunes that fall dry during certain parts of the seasonal flows. From the collected material it follows how conscious Indian farmers are of microclimate management and manipulation issues. Initially the young seedlings are watered with a hand-held watering can and later they take to the moisture levels themselves. The young plants are protected against frost and wind by erecting hedges of *Saccharum munja* at an angle of about 45° to the trench, across the direction of the wind. During summer, the earlier erected grass is spread on the sand and it protects the vines and fruits from direct contact with hot sand. This kind of traditional knowledge is confirmed by Box III.2.8 of Sect. III.2.1.(f), showing its importance for other groups of Indian farmers in the work of Murthy (2008). It is initially surprising that so few agrometeorologists have followed these traces, that we originally already started to draw in the eighties (Part I and Sect. III.2.1.(f)). But it is of course just due to a lack of research focus on the livelihood of farmers and their actual problems.

It is, however, good to know that this indigenous technique was already documented in an Indian Council of Agricultural Research (ICAR), New Delhi, publication "Validation of indigenous technical knowledge in agriculture", about a project on collection of documentation and validation of such knowledge. A study of raising cucurbitaceous crops in sand dunes under water scarcity condition was validated by the Division of Agricultural Extension of ICAR. It was concluded that this practice of vegetable growing during off season without irrigation was technically feasible and economically viable. This is a rare and precious example of validation of an innovative agrometeorological service developed by farmers for farmers. It is a precondition for further dissemination of this kind of practices, for example after calamities have stuck indigenous communities (Stigter et al. 2003).

The seventh protocol, *Agrometeorological Information for the Prevention of Forest and Wild Land Fires (Cuba)*, is an example of using (and comparing) institutionally empirical indexes in forecasting forest and plantation fires. The procedures described are carried out both in the meteorological stations and in the provincial office. Subsequently processed as an agrometeorological service, of the category E., supplemented with information from drought and weather forecasts (as services of the category F. and H.), it is transmitted from de Meteorological Center (automatically, and in some cases by phone) to the command post Forest Services in Villa Clara, agricultural enterprises, insurances sectors and government authorities.

In order to strengthen the surveillance system at the local level, the weather stations can provide this service to the units closest to the eventual request.

Validation and effectiveness of the service appear to be evaluated in partnership between forest authorities and the Meteorological Centre. This considers the number of fires detected during the season and agrometeorological conditions provided. No validation results were reported. It is great that validation is here part of the exercise from the beginning. Because it was noted that the characteristics of forest fires in Villa Clara did not differ significantly from the rest of the country, in addition to corroborating that the influence of extreme temperatures, relative humidity and accumulated rainfall at the beginning of the fires are crucial for their development, this makes the future spread to other provinces very feasible.

It is interesting to note that there is indeed ample scope for extension and generalization of the forecasting system to all comparable locations. The main constraint is availability and representativeness of meteorological data, again something we have come across rather often in agrometeorological services applications (Chaps. IV.6, IV.9 and IV.17). Consideration should again be given in a wider spread service to the validity of the indices used. As a difference with other countries, it is mentioned that in Cuba this service works at the local level, not at the national level. For a relatively small country, that is more surprising than in the case of say China. However, it very much depends on the value that national authorities give to a certain field of activities. With Cuba suffering from many disasters, where forecasting, preparedness and immediate decision making based on weather and climate are very important, such as with hurricanes, they are very well organized in these fields (Rivero Vega, Personal Communication 2008/2009).

The eighth protocol, *Furrow Planting and Ridge Covering with Plastic for Drought Relief in Semi-arid Regions (China)* is another simple microclimate management technique, as an agrometeorological service of the category B., reported from various places in China but also easily visible elsewhere in the world. Again this is also an example of land as well as water management with agrometeorological assistance (Category J.). Focused supportive research was reported here to exist for winter wheat and there is locally existing literature. One of the big difficulties encountered in China, on which we will come back later also in this Part II, is the low availability of reports on such issues in English. This has been my main reason to try, since 1997, to co-establish a program in China, on the collection and validation of such examples, on which we then should publish in Chinese and English.

Overall, there is of course no difference in precipitation received by the surfaces above ridges, furrows and level soils, but a rainfall reallocation is taking place between the plastic covered ridges and furrows. The water flows from the ridges to the furrows. And the result then is that much water is stored in the furrows, e.g. a 20 mm rainfall per unit of surface is equivalent to a 40–50 mm falling on the furrows. This enhances the plant available soil moisture.

This is a form of water harvesting on a small scale but over a large surface. In addition, soil evaporation is reduced by the film cover and this has another positive effect on moisture conditions, because more water remains available to the plants when the roots are able to reach it. The average daily mean soil temperature increased because of the film cover over the ridge, also in the furrow, at different depths. At 5 cm soil depth, for example, the temperature was raised in the order of 2° in the ridge and more than 0.5 a degree in the furrow, respectively. Before the wheat stops growth in the winter, soil temperature of the furrow at 10 and 15 cm was increased with less than a degree compared to level soil.

It is argued here, as in some other Chinese examples later on, that new focused research support can assist in the expanded and integrated use (that is further institutionalization) of these technologies in different regions according to the local natural conditions, such as climate, soil, topography and crop planting methods. From the view point of a rational utilization of natural water resources, weather and climate information should be available from the Provincial Meteorological Administrations and understood as a priority by the extension services concerned. This would mean that these extension services should also be trained in the establishment and validation of such agrometeorological services. The way this should reach the farmers in China will be discussed later in this part of the book.

The ninth protocol, *Design of On-Station Alley Cropping Trials on Flat Land in the Semi-arid Tropics (Kenya)*, is a report on very early on-station focused supportive research for the design of rain fed alley cropping agroforestry systems without the use of additional fertilizers on flat land in semi-arid areas. It is explained in this case study that alley cropping belongs to a large range of traditional and more recent attempts to make use of benefits of microclimate manipulation in tree intercropping. It is therefore basically of the category B. with again the possibility to consider it as a case of the J. category for land management.

The influence of trees on microclimate, particularly radiation and wind, so also soil and air temperature microclimate, heavily depends on heights and distribution patterns of the trees. In our alley cropping example dealt with here, the trees remained low, bush like, and their influence on radiation, wind and temperature in the rows where the crops were grown remained quite limited to the tree/crop interface and the earlier growth stages. In fact below surface soil conditions were influenced most by the presence of the alley trees. As soon as we work with hedges, shelterbelts and/or scattered trees of sufficient height to considerably influence the wind regime, also the other microclimatic factors are more seriously influenced. This includes rainfall redistribution after interception by the trees.

The quantitative assessment of the microclimatic effects of hedgerows and mulching in an alley cropping system was nevertheless important for evaluating the potentials of this cropping combination. It was even more important for semi-arid environments, where the experience is more limited. However, such attempts were rare and that made us decide to perform the agrometeorological service concerned. We have argued in Chap. IV.9 on the general importance of field quantification under such conditions. This study was particularly successful in developing new quantitative approaches for tropical conditions as to quantification of shade, soil temperature and soil moisture (Mungai et al. 1997, 2000).

It was shown in this work that yield increases due to tactical mulch incorporation were insufficient in the replacement agroforestry applied. Below a threshold rainfall, yields were even less than those in the controls (see also Box III.3.16 in Sect. III.3.4.(II)). It is argued also in this case study that the age of the agroforestry system also plays a role in these matters of competition, but influenced by the pruning regime applied to obtain the mulch for incorporation into the soil or distribution over the soil.

In alley cropping in semi-arid areas root pruning can not be exercised because this would limit even more the biomass production necessary for obtaining the mulch to be applied. In intercropping with hedges and scattered trees as well as with shelterbelts, where mulch use of loppings is not applied, tree root pruning successfully limits the competition of the trees with adjacent crops, particularly when the trees get older. However, tree growth is influenced by root pruning, depending on the pruning system applied and the rooting patterns of trees.

So, although the agrometeorological service came up with a largely negative advice, it was at the time an important service to be performed. In this case it was a validation of attempts that had been somewhat successful in the sub-humid tropics, but could definitely not been extended to flat land in the semi-arid tropics.

The tenth protocol, *Early Snow Melting Through Surface Spread of Soil Material (India)*, is again an example of attempts to study traditional techniques of microclimate improvement for a better understanding and for possible transfer to other places, eventually in a modified form. It is therefore of the B. category again, but may also be considered again as a form of agrometeorological assistance to land management (J.). This is an age old practice followed since the Epic Mahabharata in Lahaul and Spiti district of Himachal Pradesh. Farmers still utilize this practice of spreading the soil on snow for early melt of snow. This helps in early vacation of the fields for land preparation for the sowing of different crops.

Darker soil absorbs more heat than white snow and this heat is partly conducted downward, causing faster melting of the snow by about 8–30 days, depending upon amount of snowfall received during the season. This helps in early sowing of the crop(s) and enables the sowing of a second short duration crop like buckwheat, rapeseed or mustard. This case is a marvellous example of traditional "mulching", changing the albedo (surface reflection) of the surface. It is of course very helpful to be able to take on a second short duration crop in snow bound areas.

It is again good to know that also this example is already documented in an ICAR publication "Validation of Indigenous Technical Knowledge in Agriculture" on collection of documentation and validation of indigenous technical knowledge. A comparative study for willow ash and fine textured soil with respect to their amount and efficacy was also already undertaken, as indicated in the protocol.

When I had started in Dar es Salaam to look around for examples of traditional knowledge and indigenous technologies that could be physically dealt with, we developed an outdoor demonstration experiment on the effect of soil albedo on soil surface temperature. This education related work was published by Stigter et al. (1984a). We also developed a physical theory on these phenomena (Stigter et al. 1984b). Finally, we used this approach to explain temperatures under mulched tea, by expressing the thermal efficiency of grass mulches as apparent soil albedos (Stigter et al. 1984c; Othieno et al. 1985).

These theoretical developments related to the interpretation of Kenyan mulch experiments for combating erosion in small farmer tea plantations, have played a large role in later modeling of mulch behaviour. The traditional mulching method for snow, changing the albedo, that was described in this protocol can be understood with such developments. Perhaps it would also help on frozen soils with light surface colors.

The eleventh protocol, *Water Use and Water Waste Under Traditional and Non-traditional Irrigation Practices (Sudan)* is another example of government requested scientific research in direct action support as agrometeorological service. It is of the J. category, but may also be considered an example of category G., because of the changes that had occurred in the modes of irrigation. In the Gezira irrigation scheme, serious symptoms of water waste had been identified from the mid 60s till the mid 80s, with modern irrigation approaches with less field attendance, especially in sorghum and groundnut fields. A serious debate among authorities on return to traditional irrigation methods or other possible solutions needed quantification of the wastes concerned. On their request a quantitative study was undertaken to this end that also should suggest ways to improve on the situation that are compatible with the local socio-economics of the use of sharecroppers.

Tenants were dissatisfied with overall maintenance of the scheme. Authorities (Ministry of Irrigation, Sudan Gezira Board) were dissatisfied with tenants' water use. These authorities were of the opinion that the farmers were wasting water by the unattended continuous (day and night) irrigation method they have evolved, especially for their private crops dura (sorghum) and groundnuts. There was the belief that remarkable savings in water would be obtained if the tenants would go back to the traditional night storage system, in which rather laborious and well-attended daytime application of water is practised.

To possibly strengthen but at least verify the arguments of those who want to change the situation, it was thought useful to accurately quantify the problems under participatory on-farm conditions. Quantitative agrometeorology has sufficiently strong methods to be able to do so. The study has revealed wastage of irrigation water in both, traditional and more recent irrigation methods, but at different rates and also differently for each crop. The waste was higher in unattended irrigation of both dura and groundnut, and the waste was larger on groundnuts. It had also larger consequences because groundnut yields drop with excess water applied. Even much of the consumptive use is economically ill invested in non fertilized dura, because with higher additional inputs the same amounts of water would give higher returns. The application differences were mainly due to the watering methods, causing different amounts of standing water, and the methods of determining the moment of irrigation. Another type of non-productive water is the readily available water retained in the soil profile at the end of each growing season.

More efficient water and farm management (e.g. weeding) in the scheme is crucial for obtaining somewhat higher yields with other external inputs remaining at the present low level. The most important measure in this respect would be to adopt a land levelling program to the practical limits possible and to apply partly or fully attended watering on small areas, as was recommended in the traditional night storage system. Minimum practical standing water in the furrows during and immediately after each irrigation must be targeted. The results strongly link the necessities of sharecropping and the unattended watering to socio-economic backgrounds. This weakens any assumption that the unattended watering practice is a mere water availability problem. Economic measures related to the payment and price of irrigation water should also be taken. The research was carried out in the Hydraulic Research Station (HRS) in Wad Medani, that directly reports to the authorities, of which many used to work there. Institutionalization therefore exists and validation is guaranteed.

The twelfth protocol, *Shelterbelt Design for Protection of Irrigation Canals and Agricultural Land from Blown Sand Encroachment (Sudan)*, is also again another example of government requested scientific research in direct action support as agrometeorological service. Like in the first protocol, the category of agrometeorological services to which it belongs is D., the disasters also here being desertification and wind blown sand. But, as many examples have shown already above, there are often double category services, because here the mode of the combating of the disaster as an agrometeorological service belongs again also to category B. A *Eucalyptus microtheca* shelterbelt, as an agroforestry technique which uses trees to protect land from moving sand encroachment, was planted by the Gezira Board and Forestry Authorities in an attempt to prevent such an invasion of sand. To understand the mechanism by which sand was settled within and in front of the shelterbelt, on their request a quantitative study was undertaken, that also needed to come up with design rules for shelterbelts to most efficiently combat such sand invasions. Such design rules must be considered an agrometeorological service to these authorities and to the farmers whose land got protected.

Contrary to its successor described in the first protocol, the agrometeorological service was immediately applied. Our results and existing literature on air movement around shelterbelts were used to indeed develop design rules for shelterbelts for sand encroachment protection. In these rules, composition and geometry of such belts were discussed as to length, width, height, permeability, direction, openings and species. Separate consideration was given to advice on trees to be used in such shelterbelt designs. Growth rate, life span and tolerance for drought, heat, pests and diseases, grazing, sand blast and sand deposition were mentioned. Canopy geometry and byproducts were considered with respect to air flow and economy.

It was proposed that dense shrubs in the front row(s), followed by tall strong trees, would do best from the windward wind reduction point of view. Some physical land treatments were suggested at the windward side of the belt, to trap some of the encroaching sand and hence increasing the life span of the belt. Some of these design recommendations, that were offered as agrometeorological service, were subsequently used in substantial belt extensions by the Authorities. These extensions for the time being successfully protect endangered parts of the Gezira Irrigation Scheme. This is at the same time a validation of the service developed. It is now proposed that the same design be used for the White Nile Sugar Scheme (west of the Gezira Scheme and east of the White Nile) that is under execution in the same affected area.

Irrigation canals could again be restored for carrying water and abandoned fields could again be taken into production, while other parts of the Gezira Scheme were protected from the beginning. The use of such shelterbelts nevertheless demands for concern about lasting sand deposition that can only be prevented if sand can be deposited/stored in the primary or secondary source areas. In a more recent development, the very poor local population living at the periphery of the belts developed *Acacia tortilis* plantings that, with controlled grazing, now protect, again for the time being, parts of the original belts. They succeed in settling the wind driven sand with these plantings in parts of the secondary source area near to the Sihaimab belts.

Sand settlement in the source areas is necessary for long term protection. Low and to a certain extent medium permeability, as well as the formation of clusters, enhance sand trapping at all sides of scattered trees and grasses, rather independent of wind direction. Scattered trees and grasses of the right kinds, densities and permeabilities have beneficial influence on wind by modifying flows in such a way that the flow capacities to carry saltating and creeping soil particles are sufficiently reduced. However, such re-vegetation has to occur over large areas. See also the first protocol. Institutionalization at the University of the Gezira of a planned TTMI-Unit has never taken place due to lack of international funding. Without such funding and lasting international collaboration, this type of research cannot be carried out at Sudanese Universities or Institutes.

The thirteenth protocol, *Design of Improved Underground Storage Pits (Matmura) for Sorghum in Cracking Clays (Sudan)*, is an example in which good farmer surveys among very poor farmers contributed from the beginning to a better approach of the problems, taking the results of farmers' experiments into account. Extension problems were then recognized. For the category B., the advices are now on design rules on mainly below ground microclimate manipulation. Predictions of climate changes (category F.) were at the basis of these developments that therefore also may be seen as belonging to category G., with the measures remaining of the B. category.

The Jebelmuoya area in Sennar State is officially defined as rain fed, undemarcated land and has lower rainfall and poorer soils than the large mechanized farming schemes established in nearby demarcated areas. Smallholdings in Jebelmuoya vary considerably in size and are supervised by the Small Farmers' Union for Un-demarcated Areas. Unlike farmers 30 km away in the Sennar Agricultural Extension Unit, who also use the matmura system, smallholders in Jebelmuoya are not considered part of the modern sector and are, therefore, not eligible for government services. Their poverty has made the smallholder communities of Jebelmuoya particularly vulnerable to the climatic changes affecting the region as a whole. They stagger their sorghum planting in time to offset the risks of crop failure and need storage facilities that will preserve sorghum long enough to carry them through periods of crop failure and food shortage. However, at the moment there is little to encourage them to invest their meager resources in improving their matmuras. Information is scarce and practical help and advice largely unavailable.

There is an urgent need to disseminate these types of research results. The government extension services have an important role to play in this process but at the moment indigenous farmers are largely excluded from extension networks. Even though there is an extension station in the nearby town of Sennar, officials there have no communication links with farmers in Jebelmuoya.

This is again a case showing the necessity of differentiation of farmers, with government and NGOs jointly being responsible for listening to needs, getting them recognized and addressed in a participatory approach in the livelihood of these various groups of farmers. We have contributed not only by studying the storage systems but also by forcing authorities to recognize that the political decision making environment played against these target groups. Only political moves can change this situation before the knowledge obtained can be of any use to much larger groups of these farmers.

The fourteenth protocol, *Improved Design of Millet Based Intercropping Systems Using On-Station Field Research and Microclimate Manipulation (Nigeria)*, has again been left at the "focused scientific support" status. The main reason here was that the University had lost contacts with the target groups of farmers concerned, so we had their cropping and farming systems reviewed independently. The hypothesis was tested, for the most abundantly occurring intercrops in semi-arid northern Nigeria identified this way, that these systems are generally more efficient in resource use under drier conditions than sole crops. This was done for dryland intercropping, with heterogeneous mixtures derived from patterns and varieties that farmers preferred, at low densities on-station. A quantitative project was set up on resource use, with soil water balances, dry matter production and yield determinations, leading also to numerical crop productivity/water use relationships.

The agrometeorological service delivered, which is mainly again of the B. category, as most examples of the TTMI-Project (Part I and e.g. Chap. IV.9), here as a design of desirable above ground microclimates in intercropping, could also be seen as agrometeorological assistance to management of crop structural and growth resources in intercropping (category J.). The particularly intensive study of root systems also points in this direction (WMO 2010).

The most dominant crop mixtures are millet/cowpea, millet/sorghum/cowpea, millet/cowpea/groundnut, sorghum/cowpea and sorghum/cowpea/groundnut. Cowpea has a dual purpose: the grain is used for human consumption and the remaining biomass as fodder for animals. Some cowpea varieties are planted specially within the intercrops for fodder production, producing little or no grain, to take care of animal feeds during the dry season The cowpea component of the mixtures also often consists of two types, i.e. fodder and grain types that differ in growth habit and maturation period. The cereals are grown for consumption and cash. Intercropping components adopted by farmers are grown at low densities, to minimise risks and exploit resources in a good cropping season well.

All the crops sown sole and intercropped rooted beyond 1m in the loose sandy soil. Sorghum root production was greater than for millet, while both cereals produced greater root densities than cowpea. Overlap of the roots of component crops suggests competition for resources. Cowpea produced greater root densities and achieved deeper rooting when intercropped with millet and/or sorghum than sole, suggesting adaptation and competitive ability under intercropping. Rooting depths of crops were shallower in a relatively wet season than when water was limiting. Root densities and proliferation of the cereals below the surface layer were much higher in low fertility soils than when nutrients were readily available. This is immediately useful knowledge as an agrometeorological service for designing such systems.

The density and morphological characteristics of crops in association influence the microclimate within the various cropping systems. The reduction of soil radiative and heat exchanges (reduced surface soil temperature fluctuation), by a well developed low growing cowpea component in an intercropping system, is capable of reducing soil evaporation better than in the sole cereal systems and hence offers a better soil water conservation practice in the arid and semi-arid zone of Nigeria. An answer with a view of improving the cereal/legume systems in the Nigerian arid and semi-arid zones should therefore include genetically superior crop cultivars and the manipulation of the component densities along with the improvement of microclimatic variables.

The results learn that abundant organic manure in combination with agrometeorological services on intercrop manipulation related microclimate improvements may control near surface land degradation in northern Nigeria under acceptable sustainable yields. Appropriate policy environments, in economics and research, must enhance this.

The fifteenth protocol, *Design of Wind Protection Agroforestry from Experience in a Demonstration Plot of Hedged Agroforestry (Kenya)*, is reporting on demonstration plots that had been decided on in consultation with the Swiss Laikipia Research Project (LRP) in Nanyuki and local provincial authorities. A traditional maize/bean intercrop was grown in a wind protective agroforestry system with all around hedges and trees in this semi-arid region. A quantitative project was set up to determine the feasibility of this set up for the farmers that recently immigrated to this area from the Central Province of Kenya, as to yields and their sustainability compared to non-agroforestry control plots. The example was again of the B. category but because of the changes in the livelihood of those farmers, it may also be considered to be of the G. category with B. delivering the means.

Unadapted intercropping systems, introduced by immigrants, are causing low yields and land degradation. Water runoff, increasing climate variability and dietary habits of the population are also involved. In Laikipia district, deforestation, overgrazing and strong winds worsen the situation. An ideal protective mixed cropping system for these farmers would be an agroforestry system in which tree roots and crop roots colonize different soil layers and system components render services mutually. Because of initially high risks, on-station demonstration plots were chosen for introduction of such systems.

It may again be concluded that some configurations of trees, with the right distributions of biomass, can modify airflow positively and in this case sufficiently reduce mechanical damages of the protected crops and prevent the blowing off of mulches. However, strong biomass gradients, such as in gaps, as well as generation of additional turbulence should always be prevented, like this is also the case in the design of shelterbelts. The results were transferred through the local contacts that the

Laikipia Programme had developed and through direct contacts with those farmers that could be shown the results of the demonstration projects. The next step should have been further validation of improvements and alternatives on their own farms.

Farmers could be shown that combining the root pruned hedge protected system with root pruned *Grevillea robusta* trees made it economically more attractive and made it aerodynamically more efficient to diminish mechanical damage to the intercrops and improve soil water availability to these crops. The results learn that under the very difficult semi-arid conditions in Laikipia, the mulched tree cum hedge pruned agroforestry system overall helped to limit land degradation. However, the farming conditions are extremely marginal and economically more viable systems must be developed as (agrometeorological) services, to help the migrated farmers concerned.

The sixteenth protocol, *Applying Straw Mulch on Winter Wheat in Winter to Improve Soil Moisture Conditions (China)*, is another example of simple microclimate management and manipulation with the practice of mulching. So, for categorization, it definitely belongs to the B.-type. Because it is also water management that is carried out here with agrometeorological assistance, also the J.-category should be mentioned in the typology of agrometeorological services. It is again one of the management possibilities one sees applied across Asia and Africa on which much is known and much has been written, but in the developing world mostly in the gray literature. Indeed, with little exception science and third world practices are separately dealt with. The exceptions are found in Parts I and III of this book.

By comparison with uncovered winter wheat, it was shown that the soil water content of winter wheat mulched with corn straw was much better, especially before the wheat elongation stage in spring. The microclimate of wheat fields was changed evidently under straw mulching. According to field measurements, air temperature and turbulence near the surface increased, and air humidity and sub-soil temperature decreased in mulched wheat fields. Looking at the energy balance, mulching caused an increase of sensible heat flux (from a warmer surface) and a decrease of latent heat flux, so the soil evaporation from mulched wheat fields was reduced and the transpiration of wheat was increased after the elongation stage.

The total evapotranspiration over time may not have increased. It may have only changed the water consumption in time and way. In winter (mulched period), soil evaporation decreased and soil water increased; after the elongation stage, wheat transpiration increased. The water for larger soil evaporation was converted to wheat transpiration through mulching wheat in winter times.

This example will come back, as the only one, in the ten Chinese examples from another project dealt with in this Part II of the book.

The seventeenth protocol, *Using Shade Trees to Ameliorate the Microclimate, Yields and Quality of Tea (India)*, is another well known example of microclimate management and manipulation on which much has been written. The environment concerned here is harsh. Advection of hot air, high rainfall and hail storms as well as high solar radiation loads occur during the summer. Soil erosion, low water holding capacity and low fertility of silty clay loam soils are other negative conditions. The growing of shade trees is an age old technique, practised in the tea gardens in Himachal Pradesh. Shading by trees provides a number of known benefits to tea plantations including microclimatic improvement and resultantly higher growth rates and better quality of tea leaves as well as better economic returns. The category of this example is therefore again B., but it may be argued also that additionally this is an example of category I., the shade trees being additional absorbers of carbondioxide. Such an argument for cocoa was recently well received (Stigter and Abdoellah 2008) as we will explain in Sect. III.3.5.(α).

Umbrella type shade trees covering the tea gardens indeed protect them from direct sunlight, scorching heat and warm air currents. High temperatures in unshaded tea in the peak growing season drastically reduce tea yields because tea leaf temperatures exceed critical values and photosynthesis slows down. The compatible shade tree species filter solar radiation by cutting off near infrared solar flux and transmit sufficient light intensity for optimum photosynthesis. This results in lower ambient, leaf and soil temperatures and the retaining of soil moisture. It increases leaf area, number of pluckable shoots, so yields. It improves tea quality to some extent by promoting the content of caffeine, polyphenols and other taste determinants.

Generally, in the order of a 100 trees are maintained over 1 ha area. A higher density of shade tree species takes away too much of the direct sunlight, which promotes the attack of Blister Blight, which is a major tea fungal disease. With maintaining an optimum density of shade trees, also competition for water and nutrients is kept within limits. A well planned experiment could with focused scientific support test the optimum planting densities of shade tree species and quantify the benevolent effects of this system, at the same time validating the present practices.

The radiation is reduced by the order of 35–40% of total incoming solar radiation. The shading trees generally belong to leguminosae families, having the capacity of fixing atmospheric nitrogen and generating a good amount of foliage, shedding of the same at the time when the organic matter is greatly needed for building up the fertility levels and providing the requisite sunlight at the critical stage to the tea plantation. The by-products of shade trees provide fuel wood and hence save energy in the tea processing industry. It is this way a well established farming system with a built-in agrometeorological service long practised from ancient experience and innovations.

The eighteenth protocol, *Explaining Wind Protection of Coffee from Umbrella Shade Trees (Tanzania)* is very comparable to the previous example, with the difference that the shade trees on the slopes of the Kilimanjaro were particularly kept by the farmers for wind protection. But we would be inclined to categorize it as an example of D., with the wind gusts in front of showers being the natural disaster, that is combated via means under category B. and may be seen as belonging to I. as well, because of the additional carbondioxide absorption by these trees (see Sect. III.3.5.(α)).

It was indicated to us that the extension services wanted to cut the shade trees as no longer recommended. However, the farmers refused because of their experience with the wind protection provided by these trees to the coffee, particularly during high winds preceding showers. As to the quantification aspects, we had to use indirect proof here because equipment to measure vertical air movement we did not have. However, we also had observational evidence that unprotected coffee suffered damage from wind gusts while protected coffee in the same fields did not. Wind speeds measured with anemometers that quantified gusty winds with large angles of attack from the horizontal indicated the protective qualities of the shade trees and the absence of much wind tunneling. It was proven that, in comparison with unprotected coffee trees, the umbrella type shade trees indeed protected the coffee from mechanical damage of vertical air movements preceding showers. It was an agrometeorological service to recommend through the Lyamungu Coffee Research Institute to the extension service and farmers that the shade trees should be kept for wind protection.

An essential feature here was again that such problems and such an antagonism between extension people and farmers have to be brought to scientists' attention. Because of the open mind of the Director of the Coffee Research Institute, understanding what kind of research we were after when we took the initiative to visit him, he put this issue on our plate. It is one of the best roles that science can play, to be able to make such problems understood and solve the antagonism by scientific experiments and reasoning. Much indigenous knowledge can this way be tested (see also Chaps. IV.4 and IV.9) and its value be assessed for present day farming conditions in comparison to alternatives that can also be scientifically approached.

The nineteenth protocol, *Development and Establishment of a Drought Early Warning System (Cuba)*, was specially designed to be useful to governmental planners and decision makers at the local, municipal and provincial levels. But it is also used in direct services to farmers, farmers associations and governmental insurance companies. It should be categorized as E., having to be followed by drought combating measures to which it should be connected in agricultural undertakings. Expanding the definition of response farming as we recently did (Stigter 2008d), this may as well be considered an example of category C. (WMO 2010).

The "SAT" agrometeorological service of drought forecasting and early warning became operational in the Camaguey provincial weather service in November 1994, just in time to predict in September 1995 the 1995–96 winter drought disaster, which brought the government to declaring "drought emergence". This drought became known as the "Camaguey cattle emergence" and established the relevance of "SAT", of which improved versions are now available. Governmental institutions rely very heavily on the existence of this agrometeorological service. It has been fundamental in all adaptation measures and actions taken to relieve the negative impacts of drought in Camaguey, including saving nearly 100,000 heads of cattle and the maintenance of milk production levels (WMO 2010).

Services are being extended to include not only meteorological and agricultural drought but an early warning system for hydrological drought (ongoing research project). A new Web-based SATIV version is being made (ongoing research project) and a national version (ongoing research project) including pest and disease forecasts is also under construction. These three projects were approved and funded simultaneously in 2004–2005. They are all in execution now. Systems such as this should be tailored according to local technological, geographical and institutional conditions (including political organization). The system could also be improved using radar measured precipitation amounts, satellite measurements and improved water balance models. But it is clear that the use of remote sensing would be very costly for operational systems that work at daily time steps. In this sense you could say that funds are simply limiting.

A complete economic assessment has not been made because (1) social impacts and political impacts are so obvious that nobody questions the role of the system; and (2) the operation of the system is practically inexpensive and needs only a disciplined operational meteorological network and a bunch of dedicated people. Several high-level authorities have described the situation in the same terms, at different and independent occasions: "The most important achievement of the Early Warning System for Agricultural Drought in Camagüey has been the creation of a new culture on drought problems and how to deal with them. This culture doesn't exist anywhere else in Cuba and should be extended as far as possible".

The twentieth protocol, *Development of a Web Based Optimal Irrigation Calendar (Portugal)*, is another representative example of an institutionalized as well as validated agrometeorological service related to irrigation, a measure belonging to category D. With also here the annotation that it also belongs to type J., with water being again the natural resource concerned.

To combat drought and to assist water use efficiency, since 1999 an Operational and Technological Irrigation Centre (COTR) in Portugal takes advantage of ICT potential for information services to support farmers in their irrigation decisions. They provide as an agrometeorological service a web decision support system based on weather stations, the region most common soils, crops and technologies, and users data.

The farmers' irrigation needs can be obtained on line, in real time, if the user inputs his/her own water supplies. Multiple output stations are in use: internet with a web interface; internet with a personal digital assistant; mobile phone with SMS messages. Consequences of climate change will be shown by the records over time and may also be predicted (WMO 2010). The information system is supported by a relational database where the weather station and user data are stored and where information characterizing the region's most common soils, crops and technologies is also kept. This last information is also resulting from other R&D projects undertaken by COTR.

After the service implementation, farmers believe that they can improve irrigation scheduling of their crops. Every year the number of users is increasing. The biggest difficulties are related to the low use of web services by Portuguese farmers (only less than 20% frequently uses the web). Nowadays the service is based on periods of a week. Initially farmers are not receptive to such matters, but after some information or after the first year they are asking for daily information. The main objective of the service is to reach all regions of Portugal where irrigation is an important agricultural activity.

This kind of services are essential for a good irrigation scheduling, but we can't expect that farmers will use it often by themselves. It is very important to develop an irrigation extension service with technicians prepared to assist farmers, using the required tools. These technicians are connected to COTR, that will help them any time anywhere. These technicians are the extension intermediaries that can teach the farmers after they have been thoroughly trained themselves. This is the ideal built up for establishment and application of agrometeorological services.

References

Casey JF (2004) Agroforestry adoption in Mexico: using Keynes to better understand farmer decision-making. J Post Keynes Econ 26:505–521

Chambers R, Pacey A, Thrupp LA (eds) (1989) Farmer first: farmer innovation and agricultural research. Intermediate Technology Publications, London, 219pp

INSAM (2005) Results of the 2005 INSAM contest on the best examples of agrometeorological services. Available at www.agrometeorology.org under the topic "Accounts of Operational Agrometeorology" of December 6

INSAM (2007) Results of the 2006 INSAM contest on the best examples of agrometeorological services. Available at www.agrometeorology.org under the topic "Accounts of Operational Agrometeorology" of February 19

INSAM (2008) Results of the 2007 INSAM contest on the best examples of agrometeorological services. Available at www.agrometeorology.org under the topic "Accounts of Operational Agrometeorology" of April 17

KNMI (for Netherlands Government, compiled by Kees Stigter, second update) (2009) Capacity building in the area of agrometeorological services through roving seminars. Document originally distributed and presented as CAgM-XIV/INF. 4 at the XIVth Session of the WMO CAgM, New Delhi, October/November 2006, 13pp

Mungai DN, Stigter CJ, Coulson CL, Ng'etich WK, Muniafu MM, Kainkwa RMR (1997) Measuring solar radiation transmission in tropical agriculture using tube solarimeters. A warning. Agric For Meteorol 86:235–243

Mungai DN, Stigter CJ, Coulson CL, Ng'ang'a JK (2000) Simply obtained global radiation, soil temperature and soil moisture in an alley cropping system in semi-arid Kenya. Theor Appl Climatol 65:63–78

Murthy VRK (2008) Report on the project entitled "WMO-ANGRAU-DST sponsored Roving Seminars on Weather, Climate and Farmers". Available on the INSAM website www.agrometeorology.org under "Needs for agrometeorological solutions to farmer problems"

Nicholson C (2009) Bringing the internet to remote African villages. The New York Times of 2 February. http://www.nytimes.com/2009/02/02/technology/internet/02kenya.html

Othieno CO, Stigter CJ, Mwampaja AR (1985) On the use of Stigter's ratio in expressing thermal efficiency of grass mulches. Exp Agric 21:169–174

Rahimi M, Khalili A, Hajjam S, Kamali GA, Stigter CJ (2007) Risk analysis of first and last frost occurrences in central Alborz region, Iran. Int J Climatol 27:349–356

Stigter KCJ (2005) Building stones of agrometeorological services: adaptation strategies based on farmer innovations, functionally selected contemporary science and understanding of prevailing policy environments. Opening key note lecture at the FPEC Symposium, Fukuoka, Japan. J Agric Meteorol (Japan) 60:525–528

Stigter CJ (2008a) Agrometeorology from science to extension: assessment of needs and provision of services. Invited lecture at the 50th anniversary of the Chinese Academy of Agricultural Sciences, Beijing. Agric Ecosyst Environ 126: 153–157

Stigter K (2008b) Getting agrometeorology to reach all farmers. Report of a mission at the University of the Free State, Bloemfontein: 12/1-30/4/'08. Agromet Vision, Bruchem and Bondowoso, 76pp

Stigter CJ (2008c) Operational agrometeorology: problems and perspectives. In: Souvenir, International Symposium on Agrometeorology and Food Security. CRIDA, Hyderabad, pp 41–47

Stigter K (2008d) Agrometeorological services under a changing climate: old wine in new bags. WMO Bull 57(2):114–117

Stigter CJ (2009) Scientific support to the establishment and validation of agrometeorological services. SciTopics. Research summaries by experts. Elsevier, Amsterdam.
http://www.scitopics.com/Scientific_support_to_the_establishment_and_validation_of_agrometeorological_services.html

Stigter K, Abdoellah S (2008) Cocoa and climate change, can the lame help the blind? Invited Paper Presented at the “2008 Indonesian Cocoa Symposium”, Organized by ICCRI, Jember, at Sanur, Bali. An updated version is available at the INSAM website www.agrometeorology.org under “Needs for agrometeorological solutions to farming problems” of 3 November

Stigter CJ, Mjungu YB, Waryoba JM (1984a) An outdoor demonstration experiment on the effect of soil albedo on soil surface temperature. Am J Phys 52:742–744

Stigter CJ, Mjungu YB, Lutege PMB, Waryoba JM, Othieno CO, Mwampaja AR (1984b) Relationships between soil albedos and soil and air temperatures. Neth J Agric Sci 32:33–42

Stigter CJ, Othieno CO, Mwampaja, AR (1984c) An interpretation of temperature patterns under mulched tea at Kericho, Kenya. Agric Meteorol 31:231–239

Stigter CJ, Das HP, Murthy VRK (2003) Beyond climate forecasting of flood disasters. Invited Lecture on the Opening Day of the Fifth Regional Training Course on Flood Risk Management (FRM-5). Asian Disaster Preparedness Center (Bangkok) and China Research Center on Flood and Drought Disaster Reduction (Beijing), Beijing, September. Available from ADPC (Bangkok) on CD-ROM. Also available at http://www.agrometeorology.org/fileadmin/insam/repository/ADPC2mp.pdf

Winarto YT (2007) “Bull” versus “Tiger”: can the “Bull” and the “Tiger” work collaboratively? A reflection of “Farmer First” in Indonesia. Presented in “Farmer First Revisited: A Workshop on farmer innovation and agricultural research and development twenty years on”. Institute of Development Studies, University of Sussex, Brighton, December. http://www.future-agricultures.org/farmerfirst/files/T2b_Winarto.pdf

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by Stigter CJ. WMO, Geneva, in press

II.B Introduction to Part II (CMA/CAU/APMP Examples)

Kees Stigter, Zheng Dawei, Wang Shili, and Ma Yuping

The senior author of this second introduction lectures in China almost annually and is involved in research in China since 1996, initially particularly in Nanjing, Beijing and Inner Mongolia. A new project, presently core funded by the China Meteorological Administration (CMA), was originally prepared (and largely funded) by the Asian Picnic Model Project (APMP, Agromet Vision) and China Agricultural University (CAU), Beijing, from 2004 till 2007, in several missions by Zheng Dawei (CAU) and Kees Stigter (APMP) to five provinces and a preliminary project submission to CMA in 2007.

In the APMP, capacity building is the main issue and all preparations, all transfer of knowledge and all teaching take initially place in the Asian country where the project is based. Approaches can be found in the literature quoted most recently in KNMI (2009) but also in Stigter et al. (1995, 1998) See also Box II.1. Information sheets on the latest visits in September/October 2008 and some history of each case, where applicable, are mentioned in the protocols but were earlier published on the INSAM website under “Accounts of operational agrometeorology”. The case studies were named “CMA/CAU/APMP Agrometeorological Services Case Studies” I till X, abbreviated as CI till CX in List II.1. The original authors of the Chinese examples are mentioned in the draft protocols. These examples were solicited by the present authors within this project.

In comparison to earlier Chinese submissions to the INSAM contests, the ten draft protocols below are more complete in their replies to the various issues, because of the explanations given beforehand, during the visits and in a project meeting in Beijing in October 2008, to the project team that was formed by Zheng Dawei, Ma Yuping (CMA), Wang Shili (CMA) and Kees Stigter. Only Ma Yuping is not retired, the other three are working while retired. In one case, draft protocol CIX, a comparison with INSAM protocol 16 above clearly shows how much

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_3,

progress had been made over the last few years in developing knowledge on such agrometeorological services.

However, although in this specific example institutionalization has been successfully in progress, since 2003, validation exercises were not yet made. The replies under issues L, M and N show how much remains to be done here in organizing further extension work, especially more directly with the farmers concerned. The great progress made could also be assessed very well in the Ningxia examples (draft protocols CIII and CIV), in which we were involved since 2004. But exercises like this are always "work in progress" and the developing world everywhere can learn a great deal from the valuable approaches and information preliminary made available here in draft.

The senior author of this introduction has learned a lot from his Chinese counterparts and colleagues over the years. It added to his experience of the great rural problems in Africa and Asia. He believes that if one wants to understand the situation of China's rural areas, one should also take note of stories like those in Johnson (2004) and Chen and Wu (2006), that he found confirmed over the years in regular features in the official "China Daily". The latter book ends with quoted statements on the search for a way out that "China's reform is going through a major upheaval" and that "the future of China can only depend on our convictions and our efforts of today". An enlightening book on the chances that farmers have and use (and a book that we used abundantly in Stigter et al. 2007) is that of CAU's Ye Jingzhong (2002). He writes near the end that in addition to formal education, his farmers had equal access to the training and community learning organized by certain County and Township technical agencies, "though in recent years these have barely functioned". The distribution and improvement of agrometeorological services should definitely be part of genuine efforts to improve on this situation.

The senior author of this introduction also wants to draw a parallel for his role of 13 years, since 1996, in trying to collect and transfer Chinese knowledge, with that of the fifteenth century Italian traveller Niccolo Da Conti and scientists as Paolo Toscanelli, Leone Batista Alberti, Nicholas of Cusa, Mariana di Jacopo Taccola and Francesco di Georgio Martini. Following Menzies (2003), it were Da Conti and Chinese Ambassadors to Venice and Florence that brought knowledge to Italy on parts of the world found by Chinese before the European "discoveries", for example the Americas around 1422.

If we follow the reasoning in Menzies (2008), the others mentioned above were responsible after 1434 for transferring, reworking and expanding mapping material (Toscanelli), astronomical and often related mathematical knowledge (particularly Toscanelli, Alberti, Cusa), knowledge on perspective and various aspects of painting and architecture (Alberti) and knowledge on mechanical devices of all kinds (Taccola, Alberti, di Georgio), coming from at that time already well known Chinese sources. These early authors influenced Leonardo da Vinci and were instrumental in having Chinese publications of the thirteenth and early fourteenth century playing a role in getting the Renaissance moving (Menzies 2008).

Although we wish that out attempts be as successful in having a renaissance in applied agrometeorology, there is these days, as after 1434 among the mandarins

(Menzies 2003), reluctance with those in charge in China to continue this work of making Chinese experience available, particularly in Beijing, where the decisions are taken. It is very difficult to discuss these matters in English with those at the highest levels of meteorology in China. We succeeded only once. I am presently apparently the only one outside China recognizing the value of the agrometeorological services approach in China for the whole of the developing world.

The protocol CI. "Advisory and service system of crop and variety planning in Xing'an", presently mainly regards a target group that are all corn farmers (monocropping) in the Sub-Province concerned. This example combines categories A and D. (List II.2). Disasters here relate mainly to low temperatures (determining also frost free days, lengths of the growing seasons) and drought. But when heat is taken as a natural resource, it may also be seen as an example of category J.

This case consists of a computer model in which information is stored on suitable varieties of a range of locally important crops (e.g. maize, sorghum, millet, Chili peppers, pumpkin, potatoes) as a function of degree days needed for best performance during very often very short growing seasons. Frost free days go from 80 to 160. The input is meteorological (long term temperature data), agronomical (varieties, irrigation/non-irrigation, eventually soil, where important) and geographical (altitude, latitude, south slope, north slope).

The Sub-Province has roughly a 1,000 m height difference between places where crops are grown and, together with latitude and slope, this makes thermal time the most important factor governing the performance of crops under the availability of sufficient soil moisture. County wise storage of data for each crop shows maps of varieties very suitable, suitable and non-suitable in villages of the Sub-Province, based on the data of the model.

We visited an experiment station where data were collected on a range of mainly corn varieties regarding lengths of their growing season and thermal time needed for their optimal performance. In addition work was done there on crop growth in simple green houses, growing and use of animal fodder and influences on crops of the use of various sprays. We also visited a Sub-County Office that had the model on its computers and was able to give advisories at all levels, from village to government, on varieties suitable for given conditions. They regularly trained extension people, till the level of village technician, in using the model and/or asking the right questions for use of the model. The role of farmer technicians, progressive farmers that can demonstrate other farmers the use of varieties, appears important at the lowest levels. It follows from the above that the institutionalization is well on track.

The model is regularly updated with new information. It works with 30 years (1970–2000) climatological normals, but is in the process of adapting to meteorological data of the past decade. New agronomical information is regularly taken into account. These are the focused scientific supports needed. It is clear form the above that reliable meteorological and agronomical data are the crux of the matter in addition to the given geographical conditions of agricultural fields/plots.

Farmers hope for corn varieties that meet the conditions of heat, water, soil and fertilizer, or a portfolio of cultivation practices. Scientific and technical advisors are expected to offer personal guidance in the fields. The former expectation can be met with relative ease but the latter poses difficulties. Farmers are slow to accept new knowledge produced by advanced science and technology. Their mentality features "seeing is believing". Therefore, a facilitation will not be made until an intercomparison is made and demonstrated, which poses a greater difficulty to Meteorological Bureaus, especially those at the grassroot level. It is necessary to rely on leverage by other social actors.

The service network is presently considered inadequate. As the agricultural production involves more than one sector and linkages, and the agrometeorological service delivery lacks both human and financial resources, the promotion solely by agrometeorological specialists is limited. It is necessary for other actors, like agricultural technique facilitation bodies, seed services, grassroot weather stations and township meteorological assistants to take part. Support from local governments is required before the applications can be expanded at village and household levels. Although many farmers have been intensively involved, a validation exercise with farmers would help to find out how satisfied farmers actually are with the service.

First lessons to be learned here indeed are the necessity of a strong co-operation of meteorological and agronomical offices to combine trustable data (see also arguments from Lomas repeated by Stigter (2003)), and the importance of the art of reaching farmers with the information available/needed in the cascade system from Provincial Level, Sub-Provincial Level, County Level and Township Level to Village Level. At the lower levels, extension officers and village technicians must play an important role (see also Stigter et al. 2007). This should be compared with a system of Climate Field Schools as developed elsewhere in Asia (Winarto et al. 2008). The case study also illustrates the regional character of agrometeorological services of this kind, because it are the special geographical conditions of the Sub-Province that have necessitated the development of this service (see also Stigter 2008c, 2008d).

The protocol CII. "Sowing advice for spring wheat depending on the frost melting condition in the autumn irrigated top soil in Bayannur", concerns an agrometeorological service for spring wheat growers (monocropping). This case study is an example of response farming where an advisory on the earliest possible sowing date is required to have good wheat yields but too early sowing can destroy seeds/seedlings. In the categorization of agrometeorological services, this example therefore belongs to the category C, like the frost forecasting example in the third INSAM protocol above. It must be institutionalized in a similar way to be carried out well. At the same time, basically a type of meteorological forecast is involved, where it touches on the category F. It becomes of the C-type when actual in-season observations are used for corrections of general average forecasts of the developed model.

A meteorological study was made in which a regression formula was derived for determination of the most suitable sowing date from several parameters depending on temperatures and humidities in certain (pre-winter) seasonal periods. A team of four people prepares the basic advices.

An essential issue here is the necessity for the region of pre-frost autumn irrigation as the source of water for the spring wheat after melting of the frozen soils in spring. We saw this irrigation in full swing along the road. A problem is the late notification of farmers that water will be made available. In spring, working the soil before sowing and the early sowing itself are badly dependent on the top soil conditions. The meteorological data on which the local advices must be built as well as information on the actual soil conditions are reported from February onwards. This is related to soil measurements (depth of frost, speed of temperature rise correlated to rising of air temperatures) done at meteorological stations as well as reported field observations on top soil conditions.

The advices are spread by reports to the government, connections with other departments (Agronomy, Engineering/Machinery etc.) and field meetings at various levels that include extension officers and farmers in the same cascade system described already under C1. If serious adaptations are necessary, the television/radio/SMS system is used as also indicated above. We had a long discussion with a county officer, the head of a sub-county meteorological station and some farmers of sub-county villages. Broadcasting of sowing advices is via television programmes received here mostly by cable, rural radio, rural community radio, and SMS messages, that are becoming more and more popular. This latter channel of information flow appears to work well because the reception of such (short) messages is related to the small payment made for the mobile phones by each farmer in the months in which this is important. We then visited a New Countryside model village with a broadcasting centre, from where among others the advisory service on spring wheat sowing is disseminated and a Village Community Center where, again among others, this is received and broadcasted and/or disseminated otherwise.

Stigter (2008c) recently wrote: “Response farming was in this paper so far limited to rainfall events, but coping with weather and climate (and related soil) disasters (e.g. Rathore and Stigter 2007) as well as using windows of weather and climate (and often soil) opportunities are other forms of responding to weather and climate (and often soil) realities”. We have an example here.

Hot strong winds later in the season are also a climate related disaster and so are (possibly global warming related) increasing occurrences of plant diseases and pests. They experiment with sprayings to fight these ills. We also discussed with them another related service, that on the occurrence of a late devastating frost after sowing. Again farmers are advised by all communication means to produce smoke, burn straw for heating and use it for protection etc., and this way overcome the night frost. This is again in line with the reporting of for example INSAM protocol 3. When asked, the farmers indicated that in a recent case the differences in damage/final yield were very clear between fields in which this was applied (one hour before minimum temperatures, so very early in the morning) and fields where it was not applied.

Farmers hope for more accurate and timely forecasts and more preventive measures. The forecasting methods need to be improved. Field experiments and research should be strengthened, in order to improve forecast accuracy and validity and to find better measures for hazard prevention or reduction. Late spring frost and increasing pests and diseases may need further studies. This shows the additional focused scientific support that will be necessary. It is difficult to organize those farmers with less education that farm in a decentralized manner. This has inhibited the effectiveness of the service to some extent. What has been provided is a public service, but it is difficult to get feedback and to make quantitative evaluations of the effectiveness of this agrometeorological service.

Lessons learned are that, where possible, Services should collaborate to use the agrometeorological service that can best be organized by the government. Corrections as a form of response farming are necessary, applied research can help in increasing the efficiency of the service (see also Stigter 2008d). Indeed, response farming appears necessary in which actual conditions are followed for updating of the preliminary advices given earlier. This is further worked on now. Resilience should be increased from such work (Winarto et al. 2008).

It may be noted that the Mali Pilot Projects response farming issues (Part I) bear a lot of resemblance to the set-up of this case study C2: communications between a multidisciplinary team and farmers, using intermediaries, adaptation to the ongoing season, collection of input data. This also showed the importance of organizing power that appears abundantly available in China when properly mobilized. The feedback from farmers may for the time being remain a problem, because of too many steps, but was basically possible, as our discussions with selected farmers showed. This feedback for validation has to be systematically organized. That is another lesson learned.

The protocol CIII. "Improving microclimate for water melon by covering sandy soil with pebbles", is about an extremely interesting farmer innovation. Pebble-covered sandy soil watermelon production practice can be traced back for more than a century. In recent years, through multiple investigations with the melon-growing farmers, as focused scientific support, the Provincial Meteorological Bureau found that the key factor in low and instable watermelon yields was the microclimate. Rainfall is only about 175 mm, mainly in autumn. On our long journeys in September 2008, to and again south from Zhongwei, itself 200 km south of Ningxia's capital Yinchuan, we were now shown even much larger areas with the system than before, really kilometer after kilometer in this mountainous region. During the Olympics, 20,000 additional tons of watermelons have been sold. There is a risk of over-production in the following years.

The example belongs to the category B. Of course it is also an example of reducing the impacts and mitigating the consequences of drought and dry winds and therefore touches on category D as well, with drought/shortage of water resources as the disasters. So again a double category example due to the way these agrometeorological services are built up. Stigter (2006; see also WMO 2010) has described and discussed the example of water melons grown in an improved microclimate created by covering sandy soil with eight to ten cm of pebbles collected from river beds, explaining the wind erosion protection, the soil surface evaporation prevention and the warming of the seed bed so created.

It should firstly become clear that most of the few rains fall in autumn (as we experienced ourselves abundantly these days). The pebbles protect against evaporation of this water for use in early spring sowing. Without the pebbles, the soil could be dry till half a meter depth in spring! It appears that the seeds are brought into holes in the layer of pebbles that remain a cavity, over which plastic is brought by some farmers. It has been measured that at the bottom of such covered cavities the soil temperatures can be in the order of 5° higher than at the pebble surface, particularly at night. Because of the importance of early sowing due to the length of the growing season, this can be an essential frost protection issue of the method. The plastic can protect the seeds and seedlings against frost in the early days, but it is not applied by all farmers, determined also by the location.

Some details have become clearer now in discussions we had with some researchers through the Ningxia Provincial Meteorological Administration (PMA). We had for example a more than an hour long discussion on the use of these plastic strips over the places of sowing. It also appears that the sowing and replacement of (in)organic fertilizer is done by making a groove and bringing the pebbles back everywhere else but not in the sowing cavity. Over the years, this and the weight of the pebbles has the soil and pebbles mixing, which makes the system deteriorate in about 10 years. It must then either be renewed or replaced by growing Chinese date trees, which has already been successfully done in the area. To get the system re-fertilized, also irrigation water (distributed by tractor) with inorganic fertilizers is used.

In further institutionalizations, the melon growing farmers wish to get access to agrometeorological service products with additional information to address such issues as protection of seedlings from drought, frost prevention, watermelon wilt and decay, etc. The farmers are looking forward to receive timely information. For the time being, due to limited and indirect information channels, some farmers do not even know when frost may occur even when it is forthcoming. It may be too late to take any preventive measures when it comes, causing a widespread loss of seedlings. The farmers badly need relatively longer range weather forecasts and price information about various markets, in order to arrange appropriate sowing periods well in advance, and to establish links to sale channels, hoping to achieve a good harvest. From the perspective of service delivery, the future objectives are to increase service coverage and service information, expanding the agrometeorological services and products targeted to the pebble covered sandy soil watermelon production.

Due to the poverty of watermelon growing farmers in the central arid region of the Ningxia AR, their ownership of mobile phones is still quite limited. On the other hand, the telecommunication conditions are underdeveloped in the remote mountainous area.. Without cable TV, the farmers living in these areas cannot get access to TV programmes dedicated to rural areas. Therefore, the channels to get access to useful agrometeorological information by these farmers are rather limited. At present, the service is mainly delivered to the grassroot agricultural technicians and farmers through local governments and agricultural bodies at various levels, in order to guide them in adopting scientific farming practices and in agricultural disaster prevention and mitigation. Due to limited resources, it is impossible to conduct an overall survey on the economic benefits from the services covering all watermelon growing areas, which can only be roughly estimated according to the relevant statistics provided by the local governments. Such validations would be useful.

The agrometeorological studies on scientific issues (focused scientific support) concerning the pebble covered sandy soil watermelon farming are rather limited. So far neither quantitative nor qualitative indicators have been established in revealing the relationship between the watermelon growth and microclimatic and soil moisture conditions, etc. Therefore, there is lack of solid science based evidence for providing agrometeorological services. Service products and materials are therefore less persuasive than they could be. Advisories are less operational than they could be, thus being in a difficult position to satisfy all demands of local decision makers and watermelon growers.

The service is really life bringing in an area that would otherwise be too dry to grow anything. A lesson learned here is the value of paying attention to farmer innovations also in agrometeorology (e.g. Stigter 2007a). Farmer innovations and other results from farmer experiments have the largest chance of spontaneous dissemination (e.g. Stigter 2008e). The farmers in this area were threatened with migration to areas with better irrigation facilities. However, the system they developed made it possible for them to stay and earn a living from watermelons grown in an improved microclimate with high water use efficiency that they created with simple but laborious means. The focused scientific support rendered so far has been essential but limited and improvement plans should be heavily supported.

The protocol CIV. "Forecasting fungus disease conditions for wolfberries", releases the story that in studying the climatic zoning of high yielding and high quality wolfberry production, through experimental observations and investigations with wolfberry growers, it was found that a fungus disease of wolfberry, Anthracnose, had serious implications. The wolfberry trees that you see grown in large quantities, also in our journeys to and from Zhongwei, often protected by nets against birds, suffer from this Anthracnose. The Ningxia PMA has done many experiments now in which the conditions of the outbreak of the fungus were studied. The example may be seen as from the category E with D, if you consider the fungus disease a natural disaster and spraying the related measure. However, we are more inclined to bring it under "Specific weather forecasts for agriculture, including warnings for suitable conditions for pests and diseases (H)".

Although wolfberry is harvested throughout the growing season that the fruits appear, in the period mid-June–July inclusive the harvest is most abundant and 70% or more is collected during that period. In later periods, the labor is often too expensive for further harvesting and the fruits are left on the trees. The determination and forecasting of the suitable conditions of the disease is therefore most important during that earlier period. So, this is a good example of the importance of supportive applied research from which the (agro)meteorological criteria/indexes for occurrence of the disease have been derived. This is also comparable to the work on track in India (e.g. Stigter and Rathore 2008).

Since 2006, meteorological conditions favorable for the outbreak and spread of the fungus disease of wolfberry crops have been monitored annually. For example over 40 mm of rain is such a condition for epidemical outbreak. Other conditions for severe occurrence of Anthracnose have to do with numbers of rain days, relative humidity above 90%, rainfall for over 12 h and an average daily temperature over 22 °C respectively, under which germination of the fungus is very high. Although no meteorological conditions favorable for occurrence of wolfberry fungus disease were detected in 2008, as a "business as usual", the predictions on the trend of the fungus disease and the risk category forecasts were provided on a regular basis. Moreover, agrometeorological forecasts of the optimal fruit harvesting period have been issued operationally for 3 consecutive years.

The agrometeorological forecasts or warnings on occurrence and wider outbreak of the Anthracnose disease of wolfberry crops are accessible to production managers at various levels 7 days ahead, which enable them to take joint preventive or control actions in a timely manner. Among others, the forecasts and warnings are delivered to local governments, relevant agencies and farmers in forms of short range agrometeorological bulletins, thematic reports and materials that are prepared on a timely basis in support to decision making on combating the disease. The agrometeorological information is also made available through mass media like Ningxia Agricultural Website and mobile phone SMSs.

Farmers do hope that the weather service for wolfberry will be expanded to include the outbreak of major production pests such as wolfberry aphid and gall midge. Moreover, they urgently need accurate short-term weather forecasts in order to avoid losses in the chemical control of the fungus disease, wolfberry harvesting and drying. The future goal is to expand the range of relevant weather services for wolfberry. However, due to limited resources, it is difficult to achieve this goal shortly.

Although most wolfberry growing farmers have television or mobile phones to receive information, they generally don't watch or subscribe to weather service information. The important information about "early warning of wolfberry fungus disease" could be released via mobile phones across the region. However, because of cost constraints, these means can not be used for delivering conventional weather services for wolfberry growers. Farmers' awareness for adapting to new knowledge and products from advanced science and technology is rather weak. In addition, they also suspect the authenticity of early warning information received via mobile phone. Generally, disease control and timely wolfberry harvesting are conducted only after the information was confirmed by local agricultural and plant protection departments, thus leading to losses due to delays.

There are some difficulties in the implementation of the services. According to the terms of reference of agencies, information on monitoring and forecasts of crop diseases and pests should be issued by agricultural technology facilitation and plant protection departments. The Meteorological Bureaus can only issue grade forecasts of weather conditions for possible outbreak of the wolfberry fungus disease. Due to the fact that it is impossible to conduct field investigations with all farmers in the whole region after hazard occurrence, the benefit from the hazard prevention and reduction services can only be roughly estimated, based on the prices and yields of wolfberry.

If the period before and during the peak of the harvest is rather dry, the infestation is often low and no warnings are issued. In 2006, a serious outbreak was forecasted and spraying saved a lot of the crop for which the prices became excellent. As already indicated above, the work on the best fungicide to be used has also been done by the group of the Ningxia PMA. One of the lessons taught here therefore is the importance of scientific support focussed on and geared to the solution of farmers' problems, that push the research efforts. This is in line with what Kees Stigter proposed in his policy paper for the 50th anniversary of the Chinese Academy of Agricultural Sciences (CAAS) in October 2007 (Stigter 2008a).

The protocol CV. "Refined agroclimatic zoning used for planning of growing navel oranges, and protection advisory services after planting" indicates that in 2002 the Government of Ganzhou City decided to accelerate the development of navel orange industry in Gannan (southern Jiangxi). In order to meet these development targets, the Meteorological Bureaus have launched a detailed agroclimatic zoning. At he same time, they are active to deliver weather services to authorities concerned at city, county and township levels and to navel orange farmers. These tailored services are an important contribution to layouts and site selections for navel orange plantations and for the preparedness of growers for meteorological disasters once the trees have been planted and produce oranges. The target group is clearly defined as the growers of navel oranges.

This example should in first instance be seen as from the category A in List II.2, but services rather often do not come single (Stigter 2008b; WMO 2010). The part in the title on "protection advisory services after planting" was added after the emphasis put on these protection services in Ganzhou and Longnan and the morning of the following day in demonstrations in Xinfeng, where several protection stages were distinguished in the services after the basic mapping has been applied for planning purposes. This case study should therefore also be considered an example of the category D, in some cases combined with E. So again a multiple category example because of the way it was built up and carried out. The multiple natural disasters are severe cold events (extreme minimum temperatures), dry cold storms (early in the season), cold wet weather with much snow, drought (early and middle season), high temperatures and heavy rainfall (later in the season).

In a climatic study showing focussed scientific support, with a grid size of 1 ha, of Ganzhou County, the decision for areas being suitable or unsuitable for the growth of navel oranges was taken using the yardstick of degree days (over the base of ten degrees) of higher than 5,500 over the whole year and a minimum winter temperature higher than −5 °C. This resulted in unsuitability of all areas over 500 m. The this way determined "suitable area map" was fine tuned in very suitable, suitable and less suitable areas, using April to October sunshine hours and rainfall totals in average years. But such a partitioning can also be expressed in cumulative temperatures and winter minimum temperatures. This planning exercise was an institutionalized agrometeorological service from the Provincial Meteorological Bureau to the County government.

Another institutionalized part of this case study are the advisory studies related to protection from bad weather and diseases. These days, weather forecasts and such advisory services are discussed daily on cable TV, to which all farmers can listen, while some also get SMS messages. The following recent examples were given. In January/February 2008 there was a serious cold storm, with much damage in the high lands and areas grown before planning was done, but little damage in the areas approved by planning. Binding and supporting branches was advised which gave gradual recovery. In August/September 2008 there was a drought in the important period of fruit expansion. So normally irrigation will be required. However, a nearby typhoon with much rain for the area was forecasted, so an advice was given not to irrigate. Heed was taken to this message and a lot of water and efforts was saved by not irrigating as advised.

In a separate meeting in Longnan, it was indicated by the leader of the township agriculture, that irrigation with impounded water, that can be seen available everywhere, is generally done as protection to cold (in dry weather) and to drought. Fire and related smoke can be used for protection from a forecasted late spring or early autumn frost (see for example also INSAM protocol 3). In rarer years with cold wet weather, actively shedding snow or knocking ice off branches and covering young trees with straw or using it at the base helps, but it occurs less because of the planning from the earlier discussed mapping. These are examples of vulnerabilities to hazards that can be seriously reduced by temporary or permanent measures leading to impact reduction (e.g. Rathore and Stigter 2007).

Weather forecasts are also given if weather is too windy for spraying. For all operations, forecasts are given when adjustment from normal procedures is advisable. Protection for storage is also an important subject. In Xinfeng, the following protection stages were distinguished in the services after the basic mapping had been applied for planning purposes. Late March/early April, if anticyclones are threatening to bring more than 3 days of drought, there is sprinkling or other irrigation applied to prevent too much flower dropping. During heavy summer drought, furrow irrigation must assist in useful fruit expansion, although light drought can be beneficial. Too heavy rain makes drainage with furrows necessary. This is especially important during maturing phases and warnings for rains are important at this stage. More attention is planned in the future for major diseases in the rainy season. Focused scientific support could be much better developed in this case study, particularly with respect to the protective services.

Here also again communication channels of forecasts and warnings were discussed. Fruit Departments are intermediaries and have lists of farmers with their contacting information. They transform the weather information and messages into absorbable forms. Every township has extension/technician people, every village has farmer technicians. The second information channel are "Societies" for different crops such as oranges, which are loosely organized "interest groups". The third information channel are the "Cooperatives" of farmers, that are official, legal structures, like companies, that can also sign official papers. An impressive training centre we also visited.

Major demands include accurate and timely weather forecasts. Meteorological Bureaus need to continuously improve forecast accuracy and to increase channels and frequencies of service deliveries. Advices in weather information are less operational, and agrometeorologists should consider the actual local realities in agricultural production when preparing materials.

Some citrus growers are not fully aware of agrometeorological information for avoiding or reducing meteorological hazards, especially in selection of growing sites. As winter comes, due to such factors as large acreage, complex terrains, etc., farmers are often helpless, without any effective measures to take. The conventional measures like smoking and covering require large manpower, and are therefore only applicable to smaller orchards. The citrus is water demanding during the fruit expansion period. In this period the weather in Jiangxi province is mainly sunny with high temperature and less rainfall. Drought may be felt if irrigation fails.

Due to functional limitations of these Bureaus, it is not common for agrometeorologists to involve themselves in agrometeorological services for citrus site selection and hazards prevention. In collaboration with authorities concerned, technical services are mainly provided to citrus growers indirectly and direct farmer oriented services are rare. Citrus growers have low awareness of weather information and services, due to their limited coverage.

Lessons to be learned are again the multi-channel dissemination. After having heard so many examples now, it would be very helpful if validation studies were made into the efficiency of the information channels and the opinion of farmers on the services and these channels. And also on eventual alternatives or additions in services and information channels, in the ways suggested by the work of Stigter, Tan Ying et al., as presented in the CAgM workshop in New Delhi in 2006 (Stigter et al. 2007).

The protocol CVI. "Demonstration and extension of relay intercropping of late rice into lotus, enhanced by climate change", narrates that to make full use of climate and land resources in the idle late autumn season, after lotus has been harvested, based on an analysis of the local heat conditions, agrometeorologists have proposed a technique for growing white lotus interplanted with late rice. In fields normally used for growing rice, white lotus is planted as an early crop and then interplanted with late rice as a late crop. In 1990, an experiment on white lotus interplanted with late rice was launched, through which the relevant techniques were preliminarily developed. In 2006, with a poverty alleviation fund from the CMA, the case was launched to further demonstrate and promote this farming technique.

This example should mainly be seen as from the category G in List II.2. However, it has also some elements of category B, where it shows "fitting the crop to the season" aspects of microclimate management, as in Stigter's earlier categorization of microclimate related work in agriculture in the early eighties (e.g. Stigter 1994). This also comes back in the choice of earlier maturing varieties of late rice, and in microclimate issues of the lotus crop, such as in positive shading, that should be further researched.

In Sect. III.3.3.(A) we argue that the issue to attend to appears to be what multiple cropping systems have as defense strategies to extreme meteorological events that are less efficient or not available in monocropping and what science can contribute to understanding and developing such strategies. Where knowledge is operational at all in agrometeorological services, it is mainly for monocropping, perhaps for sequential cropping, but it remains marginal for mixed (inter)cropping and relay (inter)cropping, with the exception of the long recognized but insufficient exploited protection functions of trees in agroforestry applications. In other words, focused scientific support is largely absent.

In the area concerned, a double rice crop (early rice and late rice) used to be grown everywhere and is still abundantly grown. Because of the slow global warming, the seasons become longer. Now into lotus, that is sown by the end of March, early April, and gradually harvested between July and September, late rice is transplanted as a relay crop, roughly between 10 and 20 August. Because of the lotus, the rice is 45 days in the nursery, 10 days longer than normal, so the rice is transplanted later than usual.

But the land is now occupied after the lotus, that is harvested till September, while the later sown early maturing rice variety occupies the land till into November. The lotus normally fetches a high prize and the rice is an additional bonus. The lotus may lose 10% of its harvest because of the rice but under land scarcity the late rice is a useful addition. In the seventies this would not have been possible, but climate change makes it possible. Of course under early cold waves the rice will lose in production. The practice is labor intensive and time sensitive. It requires quick harvests and adequate labor input during the interplanting period. The demonstration by Meteorological Bureaus just showed their leading role, and farmers began to have economic benefits. However, large-scale promotion still calls for financial and technical support from governments at various levels.

Due to lack of labor force, some rural households failed to plant the late rice timely, resulting in shorter growth periods and lower yields. During the demonstration, Meteorological Bureaus signed contracts with farmers, according to which the former subsidized seeds and fertilizers. They would also compensate any losses compared with growing sole white lotus or a double rice crop in case of failure of the interplanting. Due to limiting funds, the scope of the demonstrations was restrained. Outreach was insufficient.

Communication on this case was effective with the meteorological communities but insufficient with local authorities and communities via such mass media as TV and newspapers. Demonstration was too short to show the advantages of lotus interplanted with rice. Due to limited resources, the demonstration lasted only 1 year, during which mid-May and early June experienced persistent low temperatures and the period of 10–13 September saw a severe cold induced dew event, both detrimental to the growth of white lotus and late rice respectively.

For extension, institutionally here eight times a kind of Climate Field Classes was organized to demonstrate and popularize the method with the target groups concerned and an office was available for training that we visited. As we earlier indicated, a comparison of such an approach (e.g. Winarto et al. 2008) with the "cascade" down coming of extension information in China would be a great last phase of the pilot projects started. The success by meteorologists with this practice in Guangchang County was recognized by the local township officials and farmers at large, who deem it a good farming practice that should be promoted widely with technical guidance covering more aspects.

Another important lesson learned here is the economically successful adaptation that is provided to a changing climate. Validation will confirm this. Only some decades ago, the present development would not have been feasible in this farming system. This is a warning for any scenarios projecting present cropping systems into the future and detailing their suffering from climate change. There are many ways for adaptation through agrometeorological services, and farmers are keen to innovate and follow up (e.g. also Winarto et al. 2008). As climate warming foresees a higher frequency of extreme and abnormal weather events, it is necessary to take into account the low temperature risks in the late stage of this farming practice. One should stay abreast of weather and climate forecasts, in order to adjust the farming practice, or to take protective measures when necessary.

The protocol CVII. "Water saving irrigation determined by soil moisture forecasting for wheat farms in the Huang-Huai-Huai Plane, Henan" deals with drought occurrence, its impact mechanism and preventive measures. A soil moisture prediction model was developed for the Huanghuai Plain, on which an integrated system was institutionalized to forecast annual soil moisture trends in the wheat/maize cycle, including a drought early warning system for the region. In recent years, available monitoring data and current forecasting cum warning capabilities were combined with facilitation of the proven water saving irrigation techniques. The Meteorological Bureau provides drought oriented agrometeorological services to increase water use efficiency and crop production, to reduce production costs and to ensure sustainable agricultural development.

The case is institutionally described for wheat. The example should be seen as from the category "Proposing means of direct agrometeorological assistance to management of natural resources (J)", with water here the natural resource that is saved, because of the irrigation reduction that is possible due to the soil moisture forecasting agrometeorology. But it is of course also again an example of E with D for drought. As focused scientific support, two methods are used for soil moisture monitoring, gravimetric monitoring in 110 soil moisture stations over the plane, and use of remote sensing results (MODIS polar orbit satellite data) with a 1 by 1 km grid. There is also use of precipitation forecasting. The target group is of a clear farming system, that of wheat growing.

Through many improved research efforts, the dynamic soil moisture monitoring has become operational with multiple remote sensing modalities. The Agrometeorological Model in Support to Decision making (AMSD) has been verified and improved for applications over the Huanghuai Plain. In addition, the soil moisture forecast is nested into the model for developing the decision making system for water saving irrigation. An objective function is applied to a comprehensive analysis from the perspective of achieving optimal economic benefits and water use efficiency, together with response advisories for decision making on whether or not irrigation will be applied, how much water will be used, and what specific dates will be chosen for irrigation.

For the purpose of forecasting when and how much to irrigate, station wise and grid wise, a drought index G is used over the growing season, calculated as $(W - E)/E$, with precipitation W (actual or forecasted) and Penman/Monteith reference evapotranspiration E (actual or forecasted up to 30 days), calculated with the FAO software (e.g. Allen et al. 1998). Numerical weather forecasts and medium and long term weather forecasts are used. In a long period of experiments, using crop phenology and crop conditions, a table for G has been constructed for the whole growing period of wheat, but also for the three phases of period of sowing, stem elongation to ear emergence and ear filling to maturity.

The approach bears similarities to agrometeorological services reported from Portugal (Stigter 2006; INSAM protocol 20 in Part II.1.A) and Cuba (INSAM protocol 3 in Part II.1.A). It confirms the importance of the FAO supported operationalization of Penman's and Monteith's basic scientific work and the supportive applied research of so many scientists over time, also in developing countries (e.g. Stigter 1978, 1979; Ibrahim et al. 1989, 2002; Oluwasemire et al. 2002). It is the ultimate proof of the importance of this basic agrometeorology, started more than 50 years ago as an example of the use of physics in agriculture (Stigter 1982a, 1982b), in applications that are benefiting many people throughout the world. In the future it will be interesting to study also here the representativeness of the soil moisture density network. We recall here the work by Ibrahim et al. (1999) in Sudan. Also the irrigation system may have to be studied in very much detail on-farm. For this we recall the work of Ibrahim et al. (2000). Water use efficiency depends on many aspects of the farming system and water waste has to be prevented by all means (Ibrahim et al. 2000, 2002).

In the current decision making approaches, agrometeorological information has been delivered to governments and authorities. They disseminate it down to farming technique facilitation stations at township and village levels, which, in turn, guide local farmers on how to plant on a guided basis and how to prevent or get prepared for agricultural hazards. However, some of this information and these services are not directly and quickly accessed by farmers. Farmers are able to get informed of general weather forecasts through some media, including TV and telephone, but too many are unable to receive detailed and practical recommendations on amounts and timing of irrigation.

A computer system calculates irrigation requirements and big farmers and business use the internet to obtain the data. The data are also provided to the provincial government who use radio and television broadcasting and meetings (lectures by technicians, village marketing) as information channels for wheat farmers, who decide themselves on the irrigation. This should be validated soonest. Farmers need timely access to agrometeorological information. A modern information and service platform and information dissemination system may be established to extend product delivery directly to the production frontlines. Efforts should be made to improve multi-channel meteorological information distribution with a focus on such bottlenecks as "last mile" access. The yield benefits here are only 6 till 7% but this is obtained with one half to one third less water, that is 1 till 2 irrigations instead of 3 till 4 irrigations for the wheat. That is the real main advantage, increased water use efficiency. Another lesson learned.

The protocol CVIII. "Forecasting peony flowering periods for various varieties and places in Luoyang city, Henan" indicates that Luoyang City in Henan Province is one of the major areas for peony cultivation. When both reputation and economic benefits of the "Luoyang Peony Show" were increasing, the acreage for peony plantation has dramatically expanded. However, the peony flowering dates vary from year to year, in particular in the context of climate warming and related abnormal events over the past decade. Times of early and late blossoming differ about 20 days, but the entire flowering period will last no more than 15 days. This is particularly due to differences in accumulated heat (thermal time). Tourists that came to see and buy the flowers were sometimes disappointed, because they were either too early and sometimes too late to enjoy the flowers. Therefore, without controlling the peony growth stages and without flowering date forecasts, the "Peony Show" could be embarrassed with inappropriate flowering dates. Especially a mistiming of the full blossoming period would disappoint visitors, and the socio-economic benefits of the show would be compromised. To prevent this to happen, accurate forecasts of flowering dates are essential.

The example should in first instance be seen as from the category "Climate predictions and meteorological forecasts (F)". With heat as a natural resource it may be considered of the category J as well. In the most sophisticated form now in use, through focused scientific support each of 10 distinguished growth stages got its own base temperature, increasing over the season. Based on the growth stages of the "Luoyang Red Peony" – a native variety – and relevant temperature data, the biological zero and effective cumulative temperature (CT) above it, as required in each individual growth stage of the 10 distinguished (germination, sprouting, leafing, round budding, flat budding, belling, coloring, initial blossoming, full blossoming and fading) of that peony, could be identified. The base temperature increases over the season. In practice, the peony growth process can be understood, and therefore predicted, based on these effective CT indicators in different growth stages with real time as well as predicted temperatures. Effective temperatures, as accumulated degree days for each of these stages, are determined and added up in a phase by phase prediction leading to flowering time.

Six years of experience led to institutionalization. Combined with weather forecasting, by middle March the flowering forecasting starts for three places in the city and it is done respectively for early, normal and late varieties of peonies, while different varieties have different flowering patterns. The three places are a center park of the city, that is hottest, so earliest. Early varieties may be used here. Well known parks, out of the centre, are later, with middle varieties, and the suburbs and mountains at the periphery of the city are latest, with later varieties also. So for people as tourists and buyers there is a long period to see and buy peonies flowering somewhere in Luoyang. Forecasts for the various varieties and places are presently not more than 1 day wrong. So validation has been done and has been positive.

Service channels are to the city government that organizes the festival and decides on its time and TV and newspapers for the flower farmers that know about the forecasts. Farmers need timely access to agrometeorological information and therefore the same suggestions as for Protocol VI. do apply. Farmers can receive weather forecasts only through television, telephone and other means, but can not get access to detailed florescence forecasts in advance. At present, forecasting service products for peony flowering are directly made available to the Luoyang City Government and the City Office for Flowers. Some agrometeorological services still can not be made available to flower growers directly.

The actual forecasts are again a collaboration between meteorologists and agronomists. The discussions on the forecast are more intense when the climate gives more problems than normal. In the open, flowering could be influenced by heating the soil for earlier flowering or using shade/ice/chemicals to delay flowering in the order of 10 days. Again the clearly commercial gains are the lesson provided here. Another lesson learned from this example is the relative simplicity of the approach using only thermal time, be it in a sophisticated way for each stage of growth. It appears that it is sometimes sufficient to use existing knowledge in a clever, often accumulating way and not necessary to have more sophisticated approaches for the purpose at hand. Of course this particularly applies to cases with an overwhelming influence of a single climatological parameter, in this case air temperature.

The protocol CIX. “Winter straw mulching increasing water use efficiency and yields in winter wheat” was reported on already in INSAM Protocol 16 in Part II.1.A. The farming system is irrigated or rainfed winter wheat cropping or corn-winter wheat cropping. For the latter: June to September for sole corn after the winter wheat has been harvested and October–June for sole winter wheat. At the beginning of winter, wheat is mulched with between 4.5 and 6 t/ha of straw mulch. For categorization, it definitely belongs to the B-type. Because it is also water management that is carried out here with agrometeorological assistance, also the J-category should be mentioned in the typology of agrometeorological services.

Stigter (1994) already 15 years ago reviewed that eight factors may be distinguished that are affected by mulch application: soil temperature; soil moisture; other soil physical properties; soil erosion; weed growth and other pests as well as diseases; soil microbial activities and other microfloral and microfaunal activities; soil chemical properties; and aerial physical properties. There are indications from research carried out in Hebei Province that over the winter wheat growing season reference evapotranspiration is decreasing since 1965 due to climate change (Li et al. 2008).

A large number of experiments has shown that straw mulching can improve moisture, fertilizer, air and heat conditions in the soil, thus reducing various ecological problems related to drought and effects such as environmental pollution due to residue burning. The practice was shown to be effective for winter wheat, maize and other crops. As focused scientific support, agrometeorologists in Hebei and Henan provinces have done some research on agrometeorological mechanisms of winter wheat straw mulching in an effort to promote a wider use of the technique. The total evapotranspiration in wheat fields may not increase, mulching may only change the water consumption in time and way. In winter (mulched period), soil evaporation decreases and soil water increases; after the elongation stage, wheat transpiration increases. The water for soil evaporation is converted to wheat transpiration through mulching wheat in winter times.

Straw is the best mulching material and the appropriate amount is 4,500–6,000 kg ha^{-1}. Before mulching, straw should be chopped up to prevent it from pressing the seedlings. The most effective mulching period for winter wheat is from the beginning of winter, which is normally in the second or last decade of December for wheat growing areas in central and southern Hebei Province. Any earlier mulching may lead to weak seedlings, while delayed mulching may shorten the effective period and its benefits will be compromised.

Straw mulching has different effects on soil moisture at different depths in different times. Compared to uncovered fields, larger differences in soil moisture content occur at the depth above 60 cm. Straw mulching can evidently improve the moisture contents of the soil surface layer. If straw mulching is made from the beginning of winter to the wheat jointing stage, the soil moisture of mulched fields will well increase compared to uncovered fields. The soil water content within a 1 m soil layer in straw mulched wheat fields is in the order of 10 mm higher at the jointing stage of winter wheat than in uncovered fields. Yield increases of generally between 6 and 15% have been measured and water use efficiency increases of more than 20%, but the latter are generally between 12 and 16% on a multi-year basis.

The ecological effects of the practice on farmland include two aspects – water and fertilizer. From the perspective of water, as we have seen, the effects are to reduce soil evaporation. In terms of fertilization, straw residues fertilize the soil after long-term physical effects and chemical decomposition, which is a long accumulative process and becomes tangible in the farmlands with multi-year straw mulching.

Much remains to be done. Various technical services and their outreach should be conducted through all mass media and communication links. For example, via newspapers and television programs, necessary information can be made available to farmers during major farming seasons and the World Meteorological Day. Using operational agrometeorological services information (e.g. decadal bulletins, radio broadcasts), among others real-time weather and soil moisture information, decisions on drought prevention and reduction, techniques and measures for production management may be produced and issued to guide agricultural production.

No validation with farmers has been performed. The training on mulching techniques should be oriented to agricultural technicians and farmers in the targeted areas for promoting wider use. Technical researchers and facilitators should go to the villages and hold training seminars, explaining basic principles and technical points, the best mulching time, amounts of straw to be used, etc. Technical material easy for farmers to read and understand about straw mulching for winter wheat should be prepared. During the growing stage of winter wheat before winter comes, technical facilitators should go to the fields to disseminate dedicated service leaflets to farmers telling them about drought prevention techniques for winter wheat

The importance of the service of advising on mulching has grown because of a generally found increase of temperature (particularly of minimum temperatures) and decrease of precipitation since the 1990s (with something as 20 mm in Hebei province), with frequently occurring drought periods in this monsoon type climate with rain falling in summer. Water requirements may therefore have increased, the decrease in reference evapotranspiration not withstanding. Wheat yields under mulching increased over the years by 5 till 15%, but more importantly the water use efficiency increased with 12–16% under an initial irrigation and subsequently rainfed conditions afterwards. This confirms the lesson learned from the Henan soil moisture services provided (protocol CVII.).

Protocol CX. "Early warning of low temperatures and less sunshine for plastic greenhouse crops in winter" states that plastic greenhouses have changed farming practices in northern China. They also tend to make full use of labor resources in rural areas, which is in line with China's conditions since farmers have greater economic returns with lower investments. No services for greenhouses did exist. The low temperature and sunshine conditions that limit production as well as more serious dangers needed an institutionalized early warning system benefiting the vegetable growers using simple greenhouses.

In the categorization used earlier in Stigter's (2008b) Hyderabad Souvenir Paper and his recent draft WMO Brochure (WMO 2010), that we have used throughout this introduction, the example belongs to category B in principle. The thermal environment is of course affected by the plastic but the production technology also leads to humidity increases that may produce vegetable diseases from fungi. Opening reduces the absolute humidity as well as the temperature, to which the growth will then adapt (see also all sections in Sub-chapter III.6.B). Of course with less sunshine, the temperatures are lower and when the weather improves the climate gets restored. Under conditions of low sunshine and at night, the plastic is covered with matting or bound straw to prevent too high reductions of temperatures in the greenhouses. So manipulation of cover over the plastic is an intrinsic part of regulating the greenhouse climate under the B category.

But the natural resources "solar radiation", "heat" and "CO2" are managed here also with agrometeorological assistance into use that otherwise would not be possible (category J), assisted by a specifically geared medium range weather forecasting for early warning. Finally, we also have to do with an early warning of low temperatures and low sunshine duration (only 3 h or less per day) over periods longer than 2 days at some crop stages and longer than a higher number of days at other crop stages. Given other services to monitor bad weather (frost, snow, ice, cold wind periods), then we talk about category E, with varying disasters.

Light (in the meaning of relatively small) losses from any source are defined as less than 30% in final yields, medium losses as 31 till 70% and heavy losses as more than 70%. For example light losses occur in cucumber when periods with 3 or less hours of sunshine per day occur for 3–6 days at the seedling stage, for 7–10 days before flowering and again for 3–6 days after flowering. Focused scientific support was in researching such damages for the most important vegetables.

The use of plasticulture in the production of horticultural crops (vegetables, small fruits, flowers, tree fruits, and ornamentals) helps to mitigate the sometimes extreme fluctuations in weather, especially temperature, rainfall and wind. Many growers experience some extremes in weather conditions during the growing season that can kill or injure the crops, or reduce marketable yield. Row covers, low tunnels and high tunnels all have the potential to minimize the effect of these extreme weather events on the crop and optimize plant growth and development in a protected environment.

Plasticulture is a technical reality. Such production systems are extending the growing seasons in many regions of the world. They encourage conservation and preservation of the environment rather than the exploitation of the land and water (see for example Sect. III.6.B.(i)). With this system, weather changes, in the form of weather forecasts, can be made available at any moment in its operational run. It focuses on the occurrence of fogy/overcast weather and its duration, essential for preparing an early warning service product in a timely manner.

The future should bring the following improvements: monitoring and analyzing the meteorological environment inside the greenhouses; studying the relationship between microclimate inside the greenhouses and the meteorological environment outside in the open; predicting environmental changes in the greenhouses using weather forecasts. It is feasible to install instruments to observe microclimate in a greenhouse, and to make comparative observations and analyses. The main target is to reduce losses caused by both excessive greenhouse humidity and crop disease outbreak, that arise from low temperature and poor sunshine, as well as to take preventive measures. There is almost no difficulty in facilitation and application of this technique, which mainly depends on the availability of daily sunshine data and future weather forecasts.

Institutionalized information dissemination of this service of the forecasting of days with less than 3 h of sunshine and some weather disasters, including low temperatures, is to the government and the farmers through weather forecasts. So, finally there is the lesson, from Hebei and more generally, of the importance of simply using existing and improved general – and of course where possible special – weather forecasts and short range climate forecasts explicitly for providing the required information as an agrometeorological service.

This is very much in line with Prof. Murthy's pleas from his work at ANGRAU in Hyderabad (Murthy 2008; WMO 2010), where published newspaper weather forecasts are used with farmers. In China, this can be by radio and TV, SMS messages on mobile phones, telephone information that can be obtained at special numbers, printed forms of some of the information and via the internet with separate weather and agricultural sites. But also here one may wonder whether Climate Field Schools (Winarto et al. 2008) would not be worth a try in the context of validation exercises. A rough estimation is that in Hebei presently 50% of the yield losses are prevented by the information given in the agrometeorological service.

List II.1 Agrometeorological services on which protocol information is given in Part II. C1 till C10 are draft examples collected in a project in China

1. *Design of sand settlement of wind blown sand using local trees and grasses (Sudan)*
2. *Agrometeorological service for irrigation advice (Cuba)*
3. *Frost Forecast Service of Inner Mongolia in 2007 (China)*
4. *Design of protection of sloping land from soil loss and water run off using hedgerow intercropping (Kenya)*

5. *Design of multiple shelterbelts to protect crops from hot dry air (Nigeria)*
6. *Seasonal vegetable growing on riverbeds – a farmers' innovation (India)*
7. *Agrometeorological information for the prevention of forest and wildland fires (Cuba)*
8. *Furrow planting and ridge covering with plastic for drought relief in semi-arid regions (China)*
9. *Design of on-station alley cropping trials on flat land in the semi-arid tropics (Kenya)*
10. *Early snow melting through surface spread of soil material (India)*
11. *Water use and water waste under traditional and non-traditional irrigation practices (Sudan)*
12. *Shelterbelt design for protection of irrigation canals and agricultural land from blown sand encroachment (Sudan)*
13. *Design of improved underground storage pits (matmura) for sorghum in cracking clays (Sudan)*
14. *Improved design of millet based intercropping systems using on-station field research and microclimate manipulation (Nigeria)*
15. *Design of wind protection agroforestry from experience in a demonstration plot of hedged agroforestry (Kenya)*
16. *Applying straw mulch on winter wheat in winter to improve soil moisture conditions (China)*
17. *Using shade trees to ameliorate the microclimate, yields and quality of tea (India)*
18. *Explaining wind protection of coffee from umbrella shade trees (Tanzania)*
19. *Development and establishment of a drought early warning system (Cuba)*
20. *Development of a web based optimal irrigation calendar (Portugal)*

CI. *Advisory and service system of crop and variety planning in Xing'an*
CII. *Sowing advice for spring wheat depending on the frost melting condition in the autumn irrigated top soil in Bayannur*
CIII. *Improving microclimate for water melon by covering sandy soil with pebbles*
CIV. *Forecasting fungus disease conditions for wolfberries*
CV. *Refined agroclimatic zoning used for planning of growing navel oranges, and protection advisory services after planting*
CVI. *Demonstration and extension of relay intercropping of late rice into lotus, enhanced by climate change*
CVII. *Water saving irrigation determined by soil moisture forecasting for wheat farms in the Huang-Huai-Huai Plane, Henan*
CVIII. *Forecasting peony flowering periods for various varieties and places in Luoyang city, Henan*
CIX. *Winter straw mulching increasing water use efficiency and yields in winter wheat*

CX. *Early warning of low temperatures and less sunshine for plastic greenhouse crops in winter*

List II.2 Stigter's categories of agrometeorological services (e.g. Stigter 2007b; 2008b; WMO 2010)

A. *Agrometeorological characterization products, such as in zoning and mapping*
B. *Advices such as in design rules on above and below ground microclimate management or manipulation*
C. *Advisories based on the outcome of response farming exercises*
D. *Measures reducing the impacts and mitigating the consequences of weather and climate related natural disasters*
E. *Monitoring and early warning exercises directly connected to such already established measures*
F. *Climate predictions and meteorological forecasts*
G. *Development and validation of adaptation strategies to changes*
H. *Specific weather forecasts for agriculture, including warnings for suitable conditions for pests and diseases*
I. *Advices on measures reducing the contributions of agricultural production to global warming*
J. *Proposing means of direct agrometeorological assistance to management of natural resources*

Box II.1

It is revealing to quote from a report on a plenary panel discussion in Stigter et al. (1995). Under the review of major issues raised during the workshop, under 1. TTMI philosophy it reads under 1.1: "The participants confirmed that training and encouragements of students to extract from their research results technologies that can be passed on to the potential beneficiaries remains an essential part of TTMI philosophy. It was therefore agreed that the section on 'Weather Advisories' should continue to feature in TTMI research theses. Although some of the ideas may reach beneficiaries directly in the course of on-farm research, it is also the duty of national TTMI-Units to develop appropriate linkages with relevant intermediaries in order to ensure that such advisories are evaluated, packaged and communicated to beneficiaries".

There was great disparity between participating countries on backing the above statement. In Sudan there was support to a very large extent, and in Nigeria to a relatively great extent as well. In Tanzania, however, this support was hardly available and in Kenya only as far as the mandates of other organizations with whom we collaborated were involved. Strangely enough, in Tanzania for a long period this self reliance idea had been a much touted national policy by its president Julius Nyerere, on which we wanted to build (Stigter 1982a), but the Universities were never bowled over by such government ideas. In Sudan, however, the local governments were a lot closer to the universities and could make such requests, even under conditions of political turmoil. In Nigeria there was an old institutional policy of closeness between research and extension in agricultural research, in Kenya this was much less the case. Moreover, in all cases the national funding of such ideas left much to be required, to say the least.

Boxes I.1 and I.2 show how much the negative attitudes to this kind of undercurrent applied science is rooted in the university education tradition that most scientists and many working in government functions in developing countries have received in the western world or from people educated in the western world. It is extremely unfortunate that this tradition appears to be largely perpetuated. It is high time indeed that developing countries get rid of this thinking (e.g. Stigter et al. 1998).

References

Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration. FAO Irrigation and Drainage Paper 56. FAO, Rome, Italy, 293pp

Chen Guidi and Wu Chuntao (2006) Will the boat sink the water? The life of China's peasants. Translated by Zhu Hong. Public Affairs Ltd, London, 229pp

Ibrahim AA, Stigter CJ, Adeeb AM, Adam HS, Jansen AE (1989) Development and validation of a shaded Piche evaporimeter for the tropics to replace humidity and wind speed data in the aerodynamic term of the Penman equation. In: Proceedings of the 4th Technical Conference on Instruments and Methods of Observation (TECIMO IV), Instruments and Observing Methods Report No. 35, WMO/TD No. 303$_r$ Geneva, pp 147–152

Ibrahim AA, Stigter CJ, Adeeb AM, Adam HS, Van Rheenen W (1999) On-farm sampling density and correction requirements for soil moisture determination in irrigated heavy clay soils in the Gezira, Central Sudan. Agric Water Manag 41:91–113

Ibrahim AA, Stigter CJ, Adam HS, Adeeb AM, Fadl OAA (2000) Farmers' practices in on-farm irrigation management in the Gezira scheme, Central Sudan. Rural Environ Eng (Japan) 38:20–29

Ibrahim AA, Stigter CJ, Adam HS, Adeeb AM (2002). Water use efficiency of sorghum and groundnut under traditional and current irrigation in the Gezira scheme, Sudan. Irrig Sci 21:115–125

Johnson I (2004) Wild grass. Three stories of change in modern China. Pantheon Books, New York, 320pp

KNMI (for Netherlands Government, compiled by Kees Stigter, second update, 2009) Capacity building in the area of agrometeorological services through roving seminars. Document originally distributed and presented as CAgM-XIV/INF. 4 at the XIVth Session of the WMO CAgM, New Delhi, October/November 2006, 13pp

Li Chunqiang, Li Baoguo, Hong Keqin (2008) Analysis of the temporal-spatial variation for reference crop evapotranspiration in Hebei Province. Paper Presented at the International Conference on Biometeorology, Tokyo (Clim Variat-O06), 6pp

Menzies G (2003) 1421, the year China discovered the world. Bantam Books, London etc, 650pp, http://www.1421.tv/

Menzies G (2008) 1434, the year a magnificent Chinese fleet sailed to Italy and ignited the Renaissance. HaperCollins, London, 368pp, http://www.1434.tv/

Murthy VRK (2008) Report on the project entitled "WMO-ANGRAU-DST sponsored Roving Seminars on Weather, Climate and Farmers". Available on the INSAM website www.agrometeorology.org under "Needs for agrometeorological solutions to farmer problems"

Oluwasemire KO, Stigter CJ, Owonubi JJ, Jagtap SS (2002) Seasonal water use and water yield of millet based cropping systems in the Nigerian Sudan Savanna near Kano. Agric Water Manag 56:207–227

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties in Asian regions. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 53–69

Stigter CJ (1978) Reference crop evaporation in Tanzania. East Afr Agric For J 44(2):112–118

Stigter CJ (1979) Comparison and combination of two recent proposals for a generalized Penman equation. Q J R Meteorol Soc 105:1071–1073

Stigter CJ (1982a) Environmental physics, agricultural research and development. Printed version of a public inaugural lecture in April 1980 upon nomination to Full Professor of Physics in July 1978. Inaugural Lecture Series, No. 30. Dar es Salaam University Press, 54pp

Stigter CJ (1982b) The use of physics in agricultural research. Int J Environ Stud 19:269–271

Stigter CJ (1994) Management and manipulation of microclimate. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York, pp 273–284

Stigter CJ (2003) The future of education, training and extension in agricultural meteorology: a new approach. In: Zheng Dawei (ed) The future of education and training in agrometeorology in China. Proceedings of a Workshop, China Agricultural University, Beijing, pp 2–11

Stigter K (2006) Agrometeorological services in various parts of the world, under conditions of a changing climate. Austin Bourke Memorial Lecture presented in the Royal Irish Academy, Dublin, in the evening of 2 March. Extended Abstract available on the INSAM website under "Accounts of Operational Agrometeorology" of March 2006

Stigter K (2007a) Agrometeorological services to prepare farmers for climate extremes and climate use. Invited Paper Presented Under "Agrometeorology and Sustainable Development" at the XVth Congress of the Brazilian Society for Agrometeorology, Aracaju, Brazil. Published as invited paper in Rev Brasil Agrometeorol 15:202–207

Stigter CJ (2007b) From basic agrometeorological science to agrometeorological services and information for agricultural decision makers: a simple conceptual and diagnostic framework. A Guest Editorial. Agric For Meteorol 142:91–95

Stigter CJ (2008a) Agrometeorology from science to extension: assessment of needs and provision of services. Invited lecture at the 50th anniversary of the Chinese Academy of Agricultural Sciences, Beijing. Agric Ecosyst Environ 126:153–157

Stigter CJ (2008b) Operational agrometeorology: problems and perspectives. In: Souvenir, International Symposium on Agrometeorology and Food Security. CRIDA, Hyderabad, India, pp 41–47

Stigter K (2008c) Agrometeorological services under a changing climate: old wine in new bags. WMO Bull 57(2):114–117

Stigter K (2008d) Coping with climate risks in agriculture needs farmer oriented research and extension policies based on participation, preparedness and resilience. Paper Presented at the First Venezuelan Agrometeorology Congress, San Cristobal, November. Later on published, with the two Appendices, in Scientia Agricola (Piracicaba, Brazil), 65 (special issue):108–115, http://www.scielo.br/pdf/sa/v65nspe/a16v65nsp.pdf

Stigter K (2008e) Policy support for capacity building in weather and climate services focused on agriculture. Based on a presentation at a Management Group Meeting of WMO/CAgM in Obninsk, Russian Federation, on June 12th. J Agrometeorol (India) 10:107–112

Stigter K, Rathore LS (2008) How to organize coping with crop disease risks of farmers in poor countries. Paper Presented at an Asian Pacific Network (APN) Finalizing Workshop of the Project "Climate and Crop Disease Risk Management: An International Initiative in the Asia-

Pacific Region" in Dhaka, Bangladesh, 10 till 14 February. Available on the INSAM web site www.agrometeorology.org under "Needs for agrometeorological solutions to farming problems" of 19 February

Stigter CJ, Wang'ati, FJ, Ng'ang'a JK, Mungai DN (eds) (1995) The TTMI-project and the "Picnic"-model: an internal evaluation of approaches and results and of prospects for TTMI-Units. Wageningen Agricultural University, Wageningen, The Netherlands, 251pp

Stigter CJ, Van den Bor W, Daane JRV, Adam HS, Mohammed AE, Ng'ang'a JK, Mungai, DN (1998) The "picnic" model for research training at African Universities: evaluation and preliminary comparison. J Agric Educ Ext 5:23–38

Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi YM (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 171–190

Winarto YT, Stigter K, Anantasari E, Hidayah SN (2008) Climate Field Schools in Indonesia: coping with climate change and beyond. LEISA Mag 24(4):16–18

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by C.J. Stigter. WMO, Geneva, in press

Ye Jingzhong (2002) Processes of enlightenment. Farmer initiatives in rural development in China. Ph.D. thesis, Wageningen University, The Netherlands, 288pp

II.C Agrometeorological Services

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_4,

II.1 <u>*Protocol number 1*</u>

Short name of the example:

Design of sand settlement of wind blown sand using local trees and grasses

A. Country/Province where the example was found

Sudan, Central Sudan, eastern side of the White Nile (south of El Geteina)

B. Institute providing the example (with address)

University of Gezira, Department of Natural Resources and Environment, Faculty of Agriculture, P.O. Box 20, Wad Medani, Sudan

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Nawal K. Nasr Al-Amin (alaminnawal@yahoo.com), C.J. Stigter (cjstigter@usa.net), Ahmed Eltayeb Mohammed (V.Chancellor@ous.edu.sd)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agro-Forestry (AF), Agrometeorological Services (AS), DEsertification (DE), DRought (DR), Natural Disasters (ND), Operational Agrometeorology (OA), Policy Matters (PM), RIsk in weather and climate (RI)

E. Natural disaster(s) and/or environmental problems to which the example is related

Desert Encroachment, Deforestation, Drought, Moving Sand

F. Way, in which the example was found, defined and collected

Several decades ago, after the African droughts of the mid-1960s, the first sand dunes appeared in the area south west of the Gezira Irrigation Scheme, although so far the longitudinal dunes on the west bank of the White Nile appeared the sand dune frontier. Rehabilitation of the sand invaded areas using desert vegetation that efficiently reduces wind speed close to the ground, this way settling sand, appears the best solution in a second front against desert encroachment. In consultation with reforestation authorities a quantitative study of sand and dune movement in the past and at present was undertaken, that also needed to come up with design rules for revegetation

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

The irrigation canals and fields that were protected by shelterbelts as first line of defense were used for growing rotations of sorghum and groundnut (as private crops), cotton and wheat (to be sold to the government). It was now the shelterbelt that was supposed to need protection from too much moving sand

H. Regions of the county (or counties) where the example can be found.

Any completely desertified area with sand movement from large source areas

I. Villages where the example can be found

Not applicable, because this was a completely desertified source area

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

In central Sudan, desert encroachment is a creeping phenomenon of which monitoring is not even carried out as to whether it fluctuates in intensity with the expansion and retraction of the Sahara, which has most recently be claimed to occur, as a consequence of well known Sahelian rainfall regime periodicities. The primary source of the sand is the Libyan desert.

Our soil surveys and interpretations of historical remote sensing pictures revealed an average desertification rate in the secondary source area of about 35 km^2 year^{-1} between 1970 and 1985. Our in-situ field calibrated saltating sand catcher measurements indicated a sand flow of something like 50,000 kg over a width of 100 m in 1 month at the height of the season. However, wind regimes in the area are not extreme, but the wind is largely unobstructed. Disappearance of vegetation is one main cause of lasting wind erosion, recurrent droughts another. Human induced establishment of trees, shrubs and grasses over large areas appears extremely difficult due to water requirements.

Quantitative agrometeorology of simple container trickle irrigation, and of wind flow and sand deposition guidance around single trees and bushes, and composite grasses, led to selection of suitable species for use in combating sand encroachment in the area. As an agrometeorological service, four species investigated appeared worth considering under the conditions of the source areas for sand settlement under windy conditions.

Leptadenia pyrotechnica *trees/bushes provide good protection against wind erosion and were found to establish well with medium frequent irrigation under the local circumstances and some protection from adverse soil and sand conditions. It is a xerophyte that reportedly had already replaced* **Acacia senegal** *by the 1960s along* *the 14th parallel in the region from El Fasher till El Obeid.* **Panicum turgidum** *grasses are difficult to establish but occur abundantly in the region and are extremely efficient in sand settlement, particularly when found in clusters caused by its dissociation. "Protection" is therefore the keyword here.* **Acacia tortilis** *tolerates well the hard conditions of the area, and establishment went reasonably well, but it usually grows into a large tree with little biomass near the surface. However, in reply to our earlier design rules for the shelterbelts, it was kept low by controlled grazing by desert dwellers that more recently settled close to the original shelterbelt. The latter is now partly protected by large-scale development of such low Acacia tortilis bushes.*

Finally, another debate is that on the suitability of **Prosopis juliflora** *(mesquite) trees. With its good sand settling properties and reasonable establishment potential it would be a suitable trial choice in our area if it were not for a government ban on its use, because of its aggressive expansion. But, like in the "***Eucalyptus** *debate", what is a disaster in one place may be a blessing under other conditions. With the example of its successful large scale use in north Kordofan, this applies to mesquite as well. We are convinced that it should be used near the White Nile also*

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

Villagers, but particularly the even poorer environmental refugees dwelling in settlements such as at the periphery of the Gezira scheme and elsewhere in the area, suffer a lot from the drifting sands. Dune fixation is only successful nearer villages and within oases. As an agrometeorological service, rehabilitation of the sand invaded areas using desert vegetation appears the only solution to all involved

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

This kind of (re)vegetation suffers tremendous degradation from destruction by desert dwellers and sometimes passing nomads, because of their understandable need for fuel wood and (diminishing) grazing. To lessen this pressure, people require guidance from government extension and NGOs

M. Difficulties of the service or information as seen by the farmers concerned

We made surveys in 20 of 77 villages affected by desertification, where settled villagers and resettled environmental refugees were distinguished as groups. A large portion of resettled villagers perceived the lifestyle of "local people" (settled villagers) as completely different. There appeared to be a general lack of awareness (>90%) among the former, most vulnerable people of the study area on how to combat desertification in spite of their high needs for fuel wood. This correlated with resettled villagers having twice the number of casual laborers (55% on average, *89% for males), twice as high illiteracy levels (90%), and three times as high (close to 95%) use of wood as main source of fuel, which was related to low-income. It also correlated with no participation in social organizations, including low exposure to extension messages regarding tree keeping and combating desertification, and no contact at all with the city, including for medical reasons.*

The surveys also revealed, as usual, the high need for alternative energy sources, for more efficient use of existing sources, for more related sources of income and for higher exposure to extension messages, which appeared statistically strongly correlated with more efforts to combat desertification. Such messages should particularly be directed to girls and women as they are mainly responsible for cutting wood for fuel

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

But what is to protect the secondary source area from degradation, once more trees, bushes and grasses get established in the rehabilitation process? It appears that another part of the secondary source area is located on the west side of the White Nile. We became convinced that the drifting sand is crossing the White Nile because detailed heavy minerals analysis proved the sand at both sides fully identical, but the transfer mechanisms can only be speculated upon.

Combating desert encroachment will have to take place on three fronts. Obviously people's awareness and participation are needed to limit wood consumption, but that of the government and NGOs to organize affordable availability of commercial wood fuel, wood efficient stoves and alternatives is also necessary. On a small scale, local people, such as those living close to the belts with grazed Acacia tortilis, should assist in revegetation. But on a large scale again the government and NGOs should make significant efforts in bold revegetation, starting in pilot projects, at both sides of the White Nile in the affected area.

Finally, scientists have to play their parts. **Prosopis juliflora** *and* **Panicum turgidum** *should be further investigated in pilot projects on the west bank of the White Nile and on the east bank facing the belts. And other vegetation, like* **Leptadenia pyrotechnica** *and other (if necessary more exotic) vegetation still to be researched should also be tried. Also the mechanisms through which drifting sand is passing from the west bank to the east bank of the White Nile should be explored, to see whether this sequence can be disturbed. Monitoring of sand arrival in north Kordofan to detect eventual fluctuations in desert expansion is also something we would very much like to see. There is a long chain of events in the rehabilitation of land suffering from desert encroachment in central Sudan, all the way from the Libyan desert. Keeping it under control is the price people have to pay for inhabiting marginal areas that start to become uninhabitable. They need the support of their governments as well as ours*

O. Chances of expanding the application of the improved example

The tree establishment experiments carried out near El-Geteina give us indications on how to approach revegetation of the area by a large corridor of scattered trees and grasses that could help settle blown sand. The first issue is appropriate watering of seedlings. Our individual drip-irrigation method seems unsuitable for very large-scale operations. Experimenting with superabsorbent polymers in tree establishment should therefore be considered seriously. The second issue is the enormous heterogeneity of the soil in composition and properties. This is due to alternating deposition and erosion, differences between soil elevations and smaller-scale undulations as well as micro-depressions and micro-relief obstacles of eroded soil surface geometrical irregularities. These create micro-differences in deposition and abrasion as well as water flow and infiltration contrasts on several scales.

From our soil sampling, it appears virtually impossible to select the most suitable places for raising trees by soil sampling and analysis. Avoiding run-on damage by height mapping exercises, the use of trial and error (by simply planting on a large scale appropriately watered species that have proven their value in the area) appears the most feasible approach. This includes selecting lower areas not yet completely filled with depositions for protected trees that need somewhat more water and selecting higher areas for such species like **Leptadenia**, **Acacia**, *particularly in the form of low bushes under controlled grazing or with other wind reducing biomass distributions, and* **Prosopis**. *With our single seedling survival experiments we have, of course, not reached the stage of natural regeneration*

P. Related examples found elsewhere in the Province (or in the country for that matter)

Not existing

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

A list of research publications is available. On what was reported above the following give the details (in chronological order):

Al-Amin NKN, Mohammed AE, Habiballa A/H, Stigter CJ (1995) The physical potential of indigenous vegetation and other means to suppress sand movement in a secondary desertification source area near the White Nile in Gezira Region, Sudan. In: Stigter CJ, Wang'ati FJ, Ng'ang'a JK, Mungai DN (eds) The TTMI-project and the "Picnic"-model: an internal evaluation of approaches and results and of prospects for TTMI-Units. Wageningen Agricultural University, The Netherlands, pp 173–181

Stigter CJ, Mohammed AE, Al-Amin NKN, Onyewotu LOZ, Oteng'i SBB, Kainkwa RMR (2002) Agroforestry solutions to some African wind problems. J Wind Eng Ind Aerodyn 90:110–1114

Stigter CJ, Al-Amin NKN, Otengi SBB, Kainkwa RMR, Onyewotu LOZ (2003) Scattered trees and wind protection under African conditions. In: Ruck B, Kottmeier C, Mattheck C, Quine C, Wilhelm G (eds) Wind effects on trees. University of Karlsruhe, Karlsruhe, pp 73–80

Al-Amin NKN, Stigter K(CJ), Elagab MAM, Hussein MB (2005) Combating desert encroachment by guiding people, wind and sand. J Agric Meteorol (Japan) 60:349–352
Al-Amin NKN, Stigter CJ, Mohammed AE (2006) Establishment of trees for sand settlement in a completely desertified environment. Arid Land Res Manag 20:309–327
Stigter CJ, Al-Amin NKN (2006) Zoning and mapping as agrometeorological services in developing countries: preconditions and requirements in a checklist for action. Paper presented at the COST/FAO/WMO/IBIMET workshop on climatic analysis and mapping for agriculture, bologna, June 2005, 28pp [Also used as PowerPoint presentation by CJ Stigter in his Roving Seminar on "Agrometeorological Services: Theory and Practice"]
Al-Amin NKN, Stigter CJ, Mohammed AE (2008) Wind reduction and sand trapping patterns within and around isolated biomass in completely desertified erosion conditions in Central Sudan. Agromet Vision, Bruchem and Bondowoso, 24pp

R. Could research assist in improvement of the service/information and how?

See under O

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

The kind of design work on holding back the desert, reported here as an agrometeorological service, could also have been carried out on desertification issues that are at the basis of the resource wars that sparked off many of the civil war situations that occurred and are occurring in Sudan. Appropriate international funding of such work should have started in the 1960s and the 1970s, 30–40 years ago, but was refused even 10 years ago for example by ISNAR

[Original submission edited by Kees Stigter; version for this book edited by Kees Stigter]

[Original submission obtained first prize in third INSAM contest of 2007]

II.2 Protocol number 2

Short name of the example:

Agrometeorological service for irrigation advice

A. Country/Province where the example was found

Cuba, Villa Clara, Santa Clara

B. Institute providing the example (with address)

Agrometeorology section, Scientific Group, Meteorological Center of Villa Clara, Postal address: Marta Abreu 59, e/Juan Bruno Zayas y Villuendas, Santa Clara, Villa Clara, Cuba, CP: 50100, Delegation of the Ministry of Science, Technology and Environment (Villa Clara), Postal address: Candelaria 6, e/Cuba y Colón, Santa Clara, Villa Clara, Cuba, CP: 50100
In collaboration with Faculty of Agricultural Science. Central University "Marta Abreu" of Las Villas

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Ismabel María Domínguez Hurtado
(ismabel.dominguez@vcl.insmet.cu; ismabelmaria@yahoo.com; ismabelmaria@gmail.com)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agro-Hydrology (AH), Agrometeorological Services (AS), DRought (DR), Agrometeorological Indicators (AI), EXtension (EX), Weather Forecasting (for agriculture) (WF)

E. Natural disaster(s) and/or environmental problems to which the example is related

Agricultural Drought, Soil Degradation, Water Resources Shortage

F. Way, in which the example was found, defined and collected

The service was established jointly by researchers at the Agrometeorology section of the Scientific Group of the Meteorological Center in Villa Clara and at the Faculty of Agricultural Sciences in the Central University "Marta Abreu" of Las Villas. The present service is based on the demands and experiences of farmer communities and of irrigation specialists of the agricultural entities of Villa Clara

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Systems for rainfed sustainable agriculture, large and small scale farms, engaged in the production of vegetables. It is also applicable in the production of grains

H. Regions of the county (or counties) where the example can be found

The example can be found in agricultural areas of the central region of the Cuba archipelago, at Villa Clara province

I. Villages where the example can be found

Santa Clara, Villa Clara, Cuba

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

The agrometeorological advisory service for irrigation in Villa Clara helps producers to achieve proper use of water resources and aims to allow users to manage water efficiently, giving the plant enough water in a timely manner.

The frequency of the information of water consumption of plants given to the producers is every 10 days. The service is trasmitted through local radio bradcasting, with specific timetables. Evapotranspiration of the previous 10-days period is evaluated, and this variable is forecasted for the current decades according to the weather forecast for the next 10 days and climate forecasting.

The agrometeorological forecasts for periods of 10 days is constructed from weather forecasts in the short and medium term and the expected trends in climate forecasting of monthly rainfall and temperatures, taking into account the local history of the behavior of the elements predicted. The agrometeorological forecasts for periods of 5 days and daily forecasts are constructed from weather forecasts in the short and medium term, in addition to the use of numerical models.

Calculation of evapotranspiration is done by the Penman/Monteith formula recommended by FAO, with the values of resistance and default coefficients resulting from the calculations for the standardized conditions in Cuba. The data used for all calculations are from the daily reports of weather stations in our province (Institute of Meteorology, INSMET), joined with reports of stations of the National Institute for Water Resources (INRH).

The outputs of the service are: (I) Estimation of the weekly water needs of crops. (II) Evaluation of the state of operation of irrigation equipment. (III) Monitoring results of the response of field crops to irrigation recommended. (IV) Availability of agrometeorological data. (V) Information collected on irrigation. The information is provided from the weather stations to the Meteorological Center, and then *transmitted directly to all the specialists and farmers by the local radio station at coordinated times.*

The service is not only used by specialists or those in the units responsible for the irrigation of agricultural production. It is also used by government authorities, such as councils of Watersheds, and Environment Management officials from territories of any kind. This service has been used into operational practice from 2005 and unexpectedly the supplied information is not only used directly for irrigation purposes, but it is also widely used by farmers of nearby villages

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

*The cost-benefit analysis has demonstrated that with the implementation of the service, farmers get an increase of 2–3% of their earnings in crops like potatoes (***Solanum tuberosum** *L), bananas (***Musa** *spp.) and tomatoes (***Lycopersicum esculentum** *Wild). Moreover, all the beneficiaries acknowledge that the service has significantly improved water management and operations, to know in advance which is the most opportune time to irrigate. These are water saving aspects.*

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

The difficulties have a very wide spectrum socially, economically and technically:

(a) The use of the system depends on decisions of the Agricultural Enterprises and of other units of the Ministry of Agriculture, which usually depend on funding.
(b) Insufficient technical personnel necessary to cover the needs of the irrigated areas in the productive units.
(c) Lack of the basic information necessary agronomically, thus weakening the scientific-technical support and rigor of the methodologies used in the irrigation scheduling. To avoid this, it must maintain a minimum number of field technicians to inspect areas that can be irrigated by applying the service.
(d) Poor communication between beneficiaries (users) and technicians responsible for the service.
(e) The tuning of the times of broadcasting the information by the radio to the work schedule of the farmers

M. Difficulties of the service or information as seen by the farmers concerned

The main difficulty found was the "synchronization" between the radio broadcasting of the agro-meteorological information and the working hours of the farmers. The problem was corrected by changing the schedule of the broadcasting of agrometeorological information. This increases the probabilities of proper use of the irrigation advices

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Goals of the service:

Enlarge the availability of the service, for example, the frequency of radio broadcasts of weather information and including local television channels to introduce a visual map.

Increase of training activities so that more farmers can apply and use a more complete information transmitted

O. Chances of expanding the application of the improved example

There is a wide scope for extension and generalization of our experience. In fact, the system can be used everywhere; it just needs a running flow of information. The main obstacles are the availability and representativeness of meteorological data

P. Related examples found elsewhere in the Country (or Countries for that matter)

Similar experiences do not exist in other localities of Cuba. However, services with similar objectives can for example be found in Navarra and Castilla-La Mancha, Spain, especially in areas with water deficits

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Yes, the following results have been obtained:

A new scientific-technical service with high added value.

The discussion of results in several scientific events:

(i) IIIrd International Congress on Irrigation and Drainage, CUBA RIEGO 2007, Ciudad de La Habana, Cuba. (On this occasion, the results discussed were selected as the best in the Panel of Climate Change, Desertification and Drought).
(ii) Event Creative Women, Santa Clara, Villa Clara.
(iii) IVth National Congress of Meteorology, December 4–8, Ciudad de La Habana, Cuba.

Three scientific papers published:

La sequía en la empresa de cultivos varios Yabú, Santa Clara, Villa Clara en el período 1977–2003. (Drought in various crops in Yabú, Santa Clara, Villa Clara in the period 1977–2003). III International Congress on Irrigation and Drainage, CUBA RIEGO 2007, Ciudad de La Habana, Cuba

Servicio radial decadal de asesoría al regante en Villa Clara (10 days outreach service for irrigation advice in Villa Clara). III International Congress on Irrigation and Drainage, CUBA RIEGO 2007, Ciudad de La Habana, Cuba

Estudio de la lluvia y la evapotranspiración de referencia en cuatro puntos representativos de la provincia de Villa Clara. (Study of rainfall and reference evapotranspiration at four representative points of the province of Villa Clara). Centro Agrícola 33(4):59–64 ISSN: 0253-5785 (2006)

A thesis to obtain the degree of master of sciences (in process)

R. Could research assist in improvement of the service/information and how?

Yes, a program dedicated to the use of satellite images has been designed by the specialists of remote sensing and fast use in the operative work is guaranteed

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

The introduction of this kind of service requires not only human resources, equipment and suitable methodologies, it also needs an in-depth knowledge of the environment in which agricultural production develops each activity, which asks attention for the following aspects:

- *Local climate and weather conditions of the agricultural season. Weather stations are an important pillar for advice on strategies that optimize the use of water. For the service to be optimal, it requires a wide network of agroclimatic quality information, covering most of the irrigated area. Time series are also essential in order to establish timetables, means and forecasts for planning irrigation.*
- *Nature of the soil in the area of pilot farms.*
- *Origin, availability and quality of irrigation water.*
- *Production (farming) systems prevailing in the area. Also, it is necessary to know their production averages, the cost of water, operating costs, operating income and net profit of each farming system.*
- *Irrigation systems uses, materials, features, operating conditions, etc. This information is essential for planning assessments of the facilities where information is used as basis for improvements and irrigation scheduling.*
- *Needs of farmers in terms of knowledge and problems in the management of irrigation: state of irrigation systems and the process of implementation of water management in their plots.*

With all this information, you can do a general analysis of the operation area. This is necessary to develop an initial plan of advanced operation, to develop alternatives of irrigation facilities, to evaluate methodologies to be selected, to follow irrigation scheduling, to give reports and to disseminate the results.

For the Irrigation Advisory Service, pilot parcels are the keys of good performance of the proposed system, in which irrigation decisions are taken using the information frequently provided. They have served as demonstration points of effectiveness, and also to win the confidence of other farmers in the use of our information service

[Original submission edited by Ismabel María Domínguez Hurtado and Kees Stigter; version for this book edited by Kees Stigter]

[Original submission obtained second prize in third INSAM contest of 2007]

II.3 <u>*Protocol number 3*</u>

Short name of the example:

Frost forecast service for Inner Mongolia in 2007

A. Country/Province where the example was found

China, Inner Mongolia Autonomous Region

B. Institute providing the example (with address)

The Hailar Road 49, Xinchen District of Hohhot, 010051 Inner Mongolia Meteorological Bureau/Climate centre of Inner Mongolia Autonomous Region

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Senior scientist: Wei Yurong (yurong_wei@yahoo.com; yurong_w@126.com)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agrometeorological Services (AS), Crop Protection (CP), Early Warning and monitoring (EW), Natural Disaster (ND), RIsks in weather and climate (RI), Operational Agrometeorology (OA), User's Needs in agrometeorology (UN), Weather Forecasting (for agriculture) (WF)

E. Natural disaster(s) and/or environmental problems to which the example is related

Frost disaster

F. Way, in which the example was found, defined and collected

This is a normal weather service to the government

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use.

All crops that will be harvested in the autumn, which are easily damaged by frost, such as vegetables, flowers, fruits and corn

H. Regions of the county (or counties) where the example can be found.

Inner Mongolia. Latitude is from 124°29′ to 101°04′, longitude is from 37°51′ to 50°41′. See also the Table under J

I. Villages where the example can be found

All villages where frost can occur and that can be reached by the forecast See also the Table under J

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

The duration of the frost free period in Inner Mongolia Autonomous Region is 70–181 days. It is shorter in Northeast, longer in Southwest.

Let's start with an example. On September 10, 2006, early morning, a farmer, Mr. Gao Qinglin, felt very cold when he went out of the door. He saw that the water that he splashed on the yard the previous day had become ice last night. He realized that his crop could be harmed. He wished he would be lucky and escape the frost damage, but the scene made him sad; almost mature soybean got frozen. The leaves were shriveled up, the whole crop wilted. His 9.3 hm^2 soybean, which are all his family cropland, were killed by frost. The loss was 6,000 RMB (nearly 800 dollars).

The table gives the initial frost date forecast of Inner Mongolia in 2007

Area		Initial frost date
Hulunbeir	Pastoral area	1–5 September
	Farm area	13–17 September
Xingan league		15–20 September
Tongliao municipality		23–27 September
Chifeng municipality	Northern	13–17 September
	Southern	23–27 September
Xilingol league	Slanting west	25–30 September
	Slanting east	5–10 September
	Centre	10–15 September
Wulancabu municipality		10–15 September
Hohhot	Downtown	20–25 September
	Northern	10–15 September
	Southern	23–27 September
Baotou	Downtown	23–27 September
	Northern	23–27 September
	Southern	13–17 September
Erdos municipality	East	23–27 September
	West	23–27 September
Bayannour municipality		25–30 September
Wuhai municipality		3–7 October
Alasan League		3–7 October

In 2007, in order to make it possible to organize protection from the frost, the Meteorological Bureau of Inner Mongolia (Provincial Meteorological Administration) published a detailed frost forecast in the whole autonomous region. It listed the average first frost appearance time, and gave the forecast date for 2007. At the same time, the publication pointed out the damage of frost and gave defense suggestions.

The defense suggestions included adopting irrigation, making fire to produce smoke in the cropland, and sprinkle against frost for protection, this way mitigating the damage from the frost.

The forecast is exchanged with all sub-regions that publish the frost forecast at their level, based on the provincial forecast, or they use the provincial forecast as their own. They issue this again to the local level government and agricultural department, while these departments will notify the next level department to do the defense work. At the same time, provincial levels broadcast the frost forecast from TV, radio and news paper and also give the defense suggestions. This is repeated at lower levels

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

Based on the feedback from several areas, the farmers and herders are satisfied with the service of frost weather forecast. At last, Mr. Gao Qinglin can protect his cropland from frost damage

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

Agrometeorological services like this just reach the agricultural department, other government institutions and media, such as TV, radio and news paper. There are no direct services to the farmer or herdsmen

M. Difficulties of the service or information as seen by the farmers concerned

Very far and poor areas, or isolated places with only few farmers or herders, with little transportation and other facilities, even no electricity, cannot be reached. For them no TV, radio and news paper. For them it is hard to get any weather news

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Every county level of the Provincial Meteorological Administration should promote such agrometeorological services; that way the service can reach more people in each area

O. Chances of expanding the application of the improved example

See above under N

P. Related examples found elsewhere in the Country (or Countries for that matter)

Many other Provincial Meteorological Administrations also did the same work. Because it was demanded by the National Meteorological Administration. Examples: Jiangxi province, Liaoniong province, Heilongjiang province etc.

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Lots of work have been done related to frost. Most of them published in Chinese journals and books. One author from CMA is Wang Chunyi

R. Could research assist in improvement of the service/information and how?

Quantitative and qualitative research on efficiency of old and new defense methods would improve the service. Studies on frost tolerance of certain crops or varieties would assist farmers to reduce frost damage. Making use of results of studies on microenvironments with less frost risk would also help

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

No

[Original submission edited by Wei Yurong and Kees Stigter; version for this book edited by Kees Stigter]

[Original submission obtained third honorary mention in third INSAM contest of 2007]

II.4 <u>*Protocol number 4*</u>

Short name of example:

Design of protection of sloping land from soil loss and water run off using hedgerow intercropping

A. Country/Province where the example was found

Kenya, Machakos area, eastern Kenya

B. Institute providing the example (with address)

Kenyan Agricultural Research Institute (KARI), P.O. Box 14733, Nairobi, Kenya

C. Researcher(s) that collected/described this example (with their e-mail addresses).

Josiah M. Kinama (JosiKinama@yahoo.com), C.J. Stigter (cjstigter@usa.net), C.K. Ong (C.Ong@cgiar.org)

D. Field(s) of Agrometeorology to which this example belongs.

[Use the fields of interest defined for registration of members of INSAM]

Agro-Forestry (AF), Agro-Hydrology (AH), Agrometeorological Services (AS), Crop Micrometeorology (CM), EXtension (EX), Policy Matters (PM), RIsks in weather and climate (RI), Topoclimatology/Mountain areas (TM), User's Needs in agrometeorology (UN)

E. Natural disaster(s) and/or environmental problems to which the example is related

Soil loss and water runoff on sloping land; competition for meager resources between trees/grasses and crops; absence of contour cropping

F. Way, in which the example was found, defined and collected

Land scarcity forces farmers in the semi-arid areas of Kenya to cultivate more sloping land. Contour hedgerows should be able to capture runoff water and soil which would otherwise be lost from hillside cultivation, and thereby compensate at least in the long run for the extra resources required for tree growth. In consultation with ICRAF, a quantitative follow-up Ph.D.-study of soil and water runoff and of soil evaporation and soil moisture with mulch involvement was set up that had to result in an improved design of hedgerow intercropping for these sloping lands and already aging hedgerows

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Maize monocropping on sloping land, often without contour cropping

H. Regions of the county (or counties) where the example can be found

Semi-arid hilly country such as that in Machakos area

I. Villages where the example can be found

Machakos and comparable places

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

Senna siamea *contour hedgerows with interrow distances of 4 m were compared "on-station" for erosion control on a 14% slope of an Alfisol, intercropped in rotation with maize and cowpea, without the use of fertilizers. There were four rows of maize or six rows of cowpea in the alleys formed by the hedgerows. The grass strips were on average more than one meter wide and their centers on average around 6.5 m apart. Each alley had five rows of maize. There were five rows of maize or nine rows of cowpea in the alleys formed by the grass strips. Heavy construction work was done to facilitate the collection of runoff and soil loss. Hedgerows were cut to a height of 25 cm 2 weeks before the onset of the rains, and the prunings spread uniformly over the soil surface. The grass strips were cut twice in the season, 2 weeks before planting and at harvest, also reducing competition with associated crops.*

Cumulative results for four consecutive seasons showed that the most successful treatment for soil loss and run off reduction was the combination of hedgerows and surface spreading of their prunings as mulch, just before the start of the two annual rainy seasons. This reduced cumulative runoff from close to 100 mm to only 20 mm and reduced cumulative soil loss from more than 100 t ha^{-1} *to only 2 t ha*$^{-1}$*.*

This was at the expense of 35% of the maize yields but only 25% of the cowpea yields, because mean rainfall was above average during the two cowpea seasons. These rather high yield depressions were due to higher competition because of aging of the hedges, that had also been used in earlier experiments, along with fertilizers. The planting of hedgerows alone, without applying the mulch, was appreciably less effective in both soil loss and runoff reduction, at the expense of even more maize yield. Mulch appeared the main soil evaporation reducing factor, but under high soil evaporation of between 50% and an upper limit of 65% of rainfall, it was not more than in the order of between a relative 5 and 10%, due to the low biomass growth in semi-arid conditions.

The grass strip results for runoff and soil loss reduction were halfway between the values for the hedges with and without mulch application, but yield reductions *were the highest of all treatments. Using only mulch but without hedges gave yields comparable to the sole crop controls, but soil loss remained more than 40 t ha^{-1} and runoff was close to double that for the combination of hedges and mulch.*

Highlighting the system design consequences for farmers, as an agrometeorological service, it has to be kept in mind that alley farming was earlier shown to be only successful if the system was adapted to the particular needs of the farmers concerned. This may be done by building as far as possible on their existing knowledge, as also part of our own approach with agrometeorological services

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

The grass strip was more effective in preventing soil erosion than the hedgerows because of the compactness and thickness of the grass strips. The latter are more effective in reducing runoff speed and trapping soil than the thinner and appreciably less dense hedgerows. For lower input farmers, grass strips and highly competitive trees with high biomass density close to the ground, even when less efficient in direct erosion control, may deliver highly needed thatching material and/or fodder and save money for durable erosion control embankment stabilization

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

High water losses from soil evaporation have been reported, while earlier work by our TTMI-project proved patterns and densities of overlapping roots between maize and **Senna siamea** *to be involved in lower yields in middle rows. For such reasons beneficial effects on crop yield are seen as often unpredictable and insufficient to attract widespread adoption. Initial enthusiasm for contour hedgerows was dampened by their slow and sporadic adoption, even in humid and sub-humid regions. Few farmers can afford to invest in any soil conservation measures which do not improve their crop yields, let alone sacrifice crop yields in drought seasons*

M. Difficulties of the service or information as seen by the farmers concerned

Removal of surface mulch resulted in an additional cumulative loss of 56 mm, but the presence of the hedgerows was much less important in reducing runoff, e.g. only an extra 23 mm was saved. This is not in line with the earlier results with the younger system, where hedges were still more important than mulches in the runoff control, but for the hedges the lower soil loss compared to mulches remained in line with the younger system.

The results learned that to reduce the trade-offs between crop productivity and erosion control on sloping land in the semi-arid tropics is the crux of the matter. It is crucial to select hedgerows and to design hedge and tree spacings that minimize competition and provide adequate erosion control. Although it was confirmed that it *is difficult to increase LEISA crop yields in the semi-arid tropics with alley cropping on sloping land, it was also observed that these strong trade-offs need not be a major deterrent to adoption by farmers, in case grass and trees provide other direct and significant benefits to farmers*

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Where farmers can afford this, frequent rejuvenation of hedgerows and greater distances between double or triple rows in combination with the use of fertilizers will considerably reduce competition with intercrops. Introduction of additional mulch from outside the system would benefit the efficiency of the system and yields

O. Chances of expanding the application of the improved example

The protective function of the mulch being so important, an advice on greater distances between hedgerows can only work jointly with increase of the numbers of trees and/or bringing in additional mulch material from outside the system. Little amounts of mulch, in our case around 2 Mg ha^{-1}*, that generally is accepted as the minimum of making agronomically sense, are known to have a reasonable physical influence, by increasing roughness, on water conservation. The results obtained here suggest that it also is a sufficient level for keeping the tolerable soil loss, the maximum erosion for sustainable crop yields, under control*

P. Related examples found elsewhere in the Province (or in the country for that matter)

Not applicable because this was on-station work

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

In the following papers (in chronological order) the details of the above basic results are explained:

Ong CK, Kinama J, Chiti R, Gichuki F, Stigter CJ, Ng'ang'a JK (1996) Agroforestry for soil and water conservation in drylands. East Afr Agric For J 62:151–162

Stigter CJ, Mungai DN, Ong CK, Kinama JM, Oteng'i SBB (2004) Testing alley cropping (contour hedgerows) in semi-arid areas on flat and sloping land: soil and water conservation, competition, yields and economic factors. Case study of economically beneficial agrometeorological applications and services and of other success stories in agrometeorology for policy matters. In: Baier W (Coord) CAgM Rep 93, WMO/TD 1202, Geneva, pp 44–47

Stigter K(CJ), Kinama J, Zhang Yingcui, Oluwasemire T(KO), Zheng Dawei, Al-Amin NKN, Abdalla AT (2005) Agrometeorological services and information for decision-making: some examples from Africa and China. J Agric Meteorol (Jpn) 60:327–330

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2005) Evaporation from soils below sparse crops in contour hedgerow agroforestry in semi-arid Kenya. Agric For Meteorol 130:149–162

Stigter CJ, Oteng'i, SBB, Oluwasemire KO, Al-Amin NKN, Kinama JM, Onyewotu LOZ (2005) Recent answers to farmland degradation illustrated by case studies from African farming systems. Ann Arid Zone 44:255–276

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2007) Contour hedgerows and grass strips for erosion and runoff control in semi-arid Kenya. Arid Land Res Manag 21:1–19

R. Could research assist in improvement of the service/information and how?

This kind of research will definitely continue. Therefore, fodder or fruit trees would be economically more preferable for farmers than trees which just provide a long lasting mulch such as **Senna siamea**. *However, it must be concluded from the results of our research reported here that for farmers under these semi-arid conditions with low mulch production, the choice remains between low but sustainable yields in hedgerow agroforestry or quickly deteriorating yields on unprotected sloping lands, due to soil erosion. The use of younger agroforestry systems or root pruned aging systems combined with fertilizers, where possible with mulch brought in from outside the system, will increase the sustainable yields obtainable in this type of hedgerow agroforestry*

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

It is our experience that the scientific level of agroforestry and agricultural journals and publications is suffering a lot from agronomical scientific traditions that do not belong in this kind of research under inhomogeneous conditions. A physical approach has been shown several times in our research endeavors to be a much easier way of handling replicated data and with comparable or better results. The feeling for this approach is often absent among agro-foresters. Our many publications about agroforestry subjects in journals like "Theoretical and Applied Climatology", "International Agrophysics", "Agricultural and Forest Meteorology", "Journal of Wind Engineering and Industrial Aerodyamics" do illustrate these points. Hidden agendas are also not uncommon in the world of agroforestry (and elsewhere)

[Original submission edited by Kees Stigter and Josia Kinama; version for this book edited by Kees Stigter]

[Original submission obtained first honorary mention in third INSAM contest of 2007]

II.5 Protocol number 5

Short name of example:

Design of multiple shelterbelts to protect crops from hot dry air

A. Country/Province where the example was found

Nigeria, Kano State

B. Institute providing the example (with address)

Shelterbelt Research Station, Forestry Research Institute of Nigeria (FRIN), P.M.B. 3239, Kano, Nigeria

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Lambert O.Z. Onyewotu (lozonye@yahoo.com), C.J. Stigter (cjstigter@usa.net), J.J. Owonubi (josephowonubi@yahoo.co.uk; DFRIN@skannet.com)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agro-Forestry (AF), Agrometeorological Services (AS), Crop Protection (CP), DEsertification (DE), DRought (DR), EXtension (EX), Operational Agrometeorology (OA), RIsks in weather and climate (RI), User's Needs in agrometeorology (UN)

E. Natural disaster(s) and/or environmental problems to which the example is related

Desertification, Drought, Advection of hot air, High intensity rainfall during showers, Low water holding capacity and low fertility of sandy soils

F. Way, in which the example was found, defined and collected

Ph.D.- and supportive M.Sc.-research at the Department of Geography, Ahmadu Bello University, Zaria, Nigeria, in collaboration with local governmental forestry organizations. Request from Government to look into protection efficiency of already established multiple shelterbelts

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Rainfed monocropping (sometimes intercropped), with farming based on low planting density millet with organic fertilizers as much as is available or can be afforded, most recently partly between multiple shelterbelts

H. Regions of the county (or counties) where the example can be found

Northern part of Kano State, not far from the frontier with Niger

I. Villages where the example can be found

Yambawa

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

In the 1970s, and especially during the great drought of 1972–1973, the scale of human suffering was so great that passionate appeals were made for official intervention to halt desertification. As a result the Kano State Forestry Department devised a programme of land rehabilitation using shelterbelts. They established, as an agrometeorological service, more than 20 km of rainfed multiple shelterbelts – eleven in total – of **Eucalyptus camaldulensis** *at Yambawa.*

The area was a strategic one. It was near an important road used by caravans and traders and many ex-labour migrants had started to settle there. The shelterbelts settled drifting sand and undulations and encouraged the return of soil protecting grasses. Farmers tried to make use of the improved microclimatic and soil conditions between the belts by growing millets.

Research also indicated that better crop yields could be achieved by using higher inputs of organic fertilizers in combination with either of the following:

- *The better design of multiple shelterbelts. It appeared that the original designers had no knowledge of any literature nor any experience on the design of shelterbelts. They also did not understand that the protection was not from mechanical damage by high winds but from dry hot air generated by the soil between the scattered trees in the local environment. It should be noted that no literature did exist anywhere on multiple shelterbelts nor on other damages than from high winds. However, much of the design literature remains pertinent to our conditions*;
- *Planting farmer friendly scattered trees at appropriate densities on the very wide land between the shelterbelts. The belts had been planted at various distances from each other, but even the shortest distance did not give protection to all the land between the belts, while at the largest distances most land was unprotected*;
- *Replacing shelterbelts by systems of scattered trees – the so-called parkland agroforestry, traditionally in use in the area – but with considerably improved densities. These trees not only deliver protection but they also have productive functions for people and/or animals.*

FRIN presented these recommendations and the outcome of the participatory experiments in several seminars attended by government extensionists and forestry staff.

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

In the late 1980s, the authors started doing research – partly farmer-managed – on the shelterbelts to find out how the situation could be improved. The results of their research enabled them to develop a number of concrete recommendations with which farmers could agree. These farmers had never been involved in the design or the planting of the belts and they were not allowed to interfere with the trees.

Research showed, for example, that no allelopathy was involved in yield suppression close to the belts, as farmers believed, but that root pruning and branch pruning were necessary precautions to reduce competition between millet and trees. The farmers took to root pruning without any difficulty because they could see its benefits. The yields close to the belts, in the quiet downwind lee zone where also the wind protection was largest, were clearly much higher due to relatively favourable water conditions and requirements. The same also applied to a much smaller zone at the windward edges of the belts

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

During the 1960s, the average annual rainfall in the city of Kano in Northern Nigeria was 825 mm. By the 1970s it had fallen to 700 mm and in the 1980s annual averages of about 650 mm were being recorded. Although rainfall remained fairly stable during the 1990s, farming under such conditions became increasingly difficult. In addition, population pressure has increased as labour migrants returned to the area after the oil boom in the South ended.

As a result holdings had become smaller and fallow periods shortened. Vegetation cover had been eliminated as trees in natural parklands had been cut down, bush burning had intensified and overgrazing had continued uncontrolled. Overused, unprotected and exposed to sun and wind, soils in the area degraded rapidly.

In 1993, it was estimated that some 3,000 people were affected by shelterbelts. Labour migrants continued to return home and the Forestry Department was convinced that these ex-farmers were returning because of the shelterbelts. This, however, was a serious misconception. Many of them were disappointed to see that shelterbelts – that appeared to offer them little benefit – had been planted on their land while they had been away.

The heavy demand for fuel wood and for wood for building houses is one important reason for establishing a shared management system for shelterbelts and woodlots. However, at the moment management is in the hands of the Forestry Department and farmers are still not involved. Fuel wood from the shelterbelts can be obtained through official channels, but only 40% of the farmers responding to a *survey indicated that they got some wood through these channels. Also, the Forest Department did not allow farmers to prune the branches because fuel wood collection and sale is an exclusive right of the authorities. They nevertheless did not carry out these rights, giving appreciable shade influence from trees on crop yields*

M. Difficulties of the service or information as seen by the farmers concerned.

The shelterbelts were established near the end of a period when many of the local farmers were employed off farm and could not be involved in the process of establishing these belts. However, in the 1970s, participatory approaches were also still uncommon and the shelterbelt program took off without the involvement of local farmers. The Forestry Department made its decisions alone and did not involve any other stakeholders in the planning process. There were no contacts between Department officials and those engineers and scientists who could have supplied some useful information on how to construct shelterbelts. In addition, the Department had very poor access to written information about previous research and experience with windbreaks.

Without access to design rules and in order to deal with the problem of seasonal changes in wind direction, shelterbelts were established at an angle to the prevailing winds. This diminished their wind protective functions in both the wet and the dry seasons. As a compromise and in order not to occupy too much farmland, the belts had also been established too far apart. The usual distance between belts is about 10 times the final height of the trees. The Forestry Department, however, spaced its belts irregularly from 15 to 25 times the estimated final height of the trees. Because the belts were so far apart, they were unable to protect all the land between the shelterbelts and much of the soil was, therefore, left unprotected against hot wind.

The width of the shelterbelts themselves was arbitrarily chosen as 30 m, which meant they still occupied about 20% of farmland. Better results would have been achieved if both the width of the shelterbelts and the space between them had been halved. The farmers disliked the shelterbelts. Their agricultural land was being occupied and our early research already showed that the shelterbelts also competed for water, light and nutrients with their other crops, while, more seriously, the shelterbelts offered limited protection to the fields they were designed to shield. Instead of Eucalyptus trees, the farmers would have preferred indigenous tree species that could have offered food, fruits, fodder or medical products. They disliked their farmland being occupied without compensation and the fact that they were not allowed to do any maintenance on the belts, such as pruning the front branches to stop the trees shading the front rows of crops, or coppicing which would have provided them with fuel wood

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

At the moment the Forestry Department does not seem to have any plans for improving the efficiency of the shelterbelts. Present policy, financial restrictions and the *lack of a tradition of participative approaches to these types of issues at the official level are important constraints. Therefore no workable solutions to the problems associated with existing shelterbelts and no other options, such as parkland agroforestry, to rehabilitate soil and stop desertification, are being developed.*

The experience of northern Nigeria confirms that soil management and rehabilitation policies must be set in the context of wider development objectives and a well-defined direction of social change, in which federal as well as state authorities in Nigeria have an important responsibility. In developing a policy of soil rehabilitation, farmers' input not only provides important insights but is also necessary for establishing effective and communal management systems. These systems should have enabled returning land-owners and farmers to get involved, and must now also be capable of evolving to meet the agro-ecological and demographic challenges of the region.

In addition to securing farmers' participation, special extension intermediaries should be trained and equipped to improve the flow of information between researchers, farmers and government authorities

O. Chances of expanding the application of the improved example

Unknown

P. Related examples found elsewhere in the Province (or in the country for that matter)

None

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Yes, a list of research publications of the group at the Ahmadu Bello University and FRIN is available. Scientifically the most important one is:

Onyewotu LOZ, Stigter CJ, Oladipo EO, Owonubi JJ (2004) Air movement and its consequences around a multiple shelterbelt system under advective conditions in semi-arid northern Nigeria. Theor Appl Climatol 79:255–262

There are also four more general publications:

Onyewotu LOZ, Stigter CJ (1995) Eucalyptus – its reputation and its roots: millet and a eucalyptus shelterbelt in Northern Nigeria. Agrofor Today, 7(1):7–8

Onyewotu LOZ, Stigter CJ, Abdullahi AM, Ariyo JA, Oladipo EO, Owonubi JJ (2003) Reclamation of desertified farmlands and consequences for its farmers in semiarid northern Nigeria: a case study of Yambawa rehabilitation scheme. Arid Land Res Manag 17:85–101

Onyewotu L, Stigter K, Abdullahi Y, Ariyo J (2003) Shelterbelts and farmers' needs. LEISA Mag 19 (4):28–29

Stigter CJ, Onyewotu LOZ, Owonubi JJ (2004) Combating desertification and reintroducing agricultural production in Sahelian conditions by appropriate planting of multiple shelterbelts, and *some simple agronomic measures. Case study of economically beneficial agrometeorological applications and services and of other success stories in agrometeorology for policy matters. In: Baier W (Coord), CAgM Rep. 93, WMO/TD 1202, Geneva, pp 40–43*

R. Could research assist in improvement of the service/information and how?

Research on a comparison of well designed multiple shelterbelts with sufficiently dense scattered trees in parkland agroforestry, in crop protection from advected hot air, would be very beneficial. Research into extension problems and joint management issues of trees and belts is urgently needed

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

None

[Original submission edited by Kees Stigter; version for this book edited by Kees Stigter]

[Original submission obtained second honorary mention in third INSAM contest of 2007]

II.6 Protocol number 6

Short name of example:

Seasonal vegetable growing on riverbeds – a farmers' innovation

A. Country/province where example was found

India in the states of Uttar Pradesh, Punjab and Himachal Pradesh

B. Institute providing the example (with address)

Dr. Rajendra Prasad, Agrometeorologist, Department of Agronomy, Agrometeorology section CSK Himachal Pradesh Agricultural University, Palampur 176 062, Himachal Pradesh, India; Dr. Virendar Singh, Extension Specialist (Soils), Research Sub Station, CSK Himachal Pradesh Agricultural University, Akrot (Una), 177 211, Himachal Pradesh, India

C. Researchers that collected/described this example (with the e-mail addresses)

Dr. Rajendra Prasad (agron@hillagric.ernet.in; rprasad57@gmail.com),
Dr. Virendar Singh (vs6789@rediffmail.com)

D. Field(s) of Agrometeorology to which the example belongs:

[Use the fields of interest defined for registration of members of INSAM]

Crop Micrometeorology (CM), RIsk in weather and climate (RI), Agro-Hydrology (AH)

E. Natural disasters (s) and/or environmental problems to which the example is related

Prevailing low temperatures during December and January, water stress during December–June and high surface sand temperatures in April–June are not conducive for remunerative agricultural enterprise on river beds (sand deposits). The specialized river bed cultivation in barren and inhospitable environments gives good returns by growing cucumber, sponge gourd, melons, pumpkins, snake gourd and bitter gourd, tomato, brinjal and capsicum etc.

F. Way, in which the example was found, defined and collected

This practice in its present form in Himachal Pradesh and Punjab is definitely not more than 40–45 years old. During 2006, while on a visit to carry out an agro-climatic field survey in Una district of Himachal Pradesh, the authors found that the farmers utilized this practice for raising vegetable crops on sandy river beds of the seasonal Swan river, flowing from Gagret to Santoshgarh areas of Una district

G. Farming system(s) in which the agrometeorological service is applied or to whom the agrometeorological service is provided for actual use

This is a farmers' innovation of seasonal vegetable growing

H. Region of the country (countries), where the example can be found

On river beds in Himachal Pradesh adjoining Punjab and Uttar Pradesh

I. Villages where the examples can be found

On river beds in the districts of Maukatsar, Faridkot, Hoshiarpur and Una in Punjab and the seasonal Swan river in Himachal Pradesh. In Uttar Pradesh, cultivation is carried out on river beds of rivers like Ganges, Gomati, Rapti, Ghaghara and Yamuna, but it is not possible to supply names of the districts

J. Describe the good example of the operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problems(s) concerned

*Muslim growers hailing from Barelli, Shahjahanpur, Rampur and Badaun districts of Uttar Pradesh have traditional inherited knowledge of this art of growing vegetables on barren, water scarce sand dunes offering an inhospitable environment. The land is hired from the local farmers @ Rs 50–100/- per kanal (400 m^2). This community has been pursuing this profession in different parts of Punjab and Himachal Pradesh, having similar agroclimatic analogues along the river/stream banks. Members of the community live in huts made of sarkanda grass (***Saccharum munja***) erected nearby for better care of their crops. They watch and ward from Neel Gai (***Boselaphus tragocamelus***), an Indian Blue Bull and an Asiatic antelope. Each family normally takes on to cultivate a 100 kanal area with Rs. 2,000–2,500 per kanal as cost of cultivation, depending upon the vegetable grown.*

First of all, the depth of the water table is tested by digging a trench by a spade. Then 3–4 sprouted seeds are placed in the east-west trenches, usually 120–240 ft long, with an inter-trench distance of 15–20 ft. It is dug depending upon the depth of the water table (normally 3 ft deep) and filled with a mixture of sand, farm yard manure and fertilizer (mostly urea) overlain with barren sand. After about 1 month, as the water table goes further down, another trench to the level of the water table is dug, adjacent to first one. It is also filled with the mixture of sand, farm yard manure and fertilizer. After few days, roots tend towards this layer to exploit nutrients and moisture. Thus the crops do not face any moisture stress. After 1 month of sowing/transplanting, same fertilizer schedule is repeated at a distance of 1.5 ft from the plants and generally two applications as enumerated above are sufficient.

The trenches for pumpkin are dug from beginning to mid of October, for bottle gourd from mid October to first week of November. For all other cucurbits, mid to end November is the optimum time. Nursery tomato, brinjal and capsicum are *raised during December. The best time for transplanting the seedlings of tomato is mid January, for brinjal and capsicum the entire month of January is suitable. Initially the young seedlings are watered with a hand-held watering can and later they take to the moisture levels themselves. The young plants are protected against frost and wind by erecting hedges of* **Saccharum munja** *at an angle of about 45° to the trench across the direction of the wind. During summer, the earlier erected grass is spread on the sand that protects the vines and fruits from direct contact with hot sand.*

It is an agrometeorological service worth putting into practice and suitable for recommendation for remunerative vegetable cultivation on sand dunes

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increases in income due to the services or information

Without advective frost conditions, average net profit of Rs. 5,000–7,500/- per kanal per crop is earned by each family

L. Difficulties encountered in introduction and use of good example of agrometeorological services or information

This practice is very good for vegetable production as it meets part of the local market demands. The major cause of concern is, however, the excessive and unscientific use of insecticides, pesticides and fertilizers etc., which is detrimental to human health as well as the environment. These activities are also causing instability in the riverbed, as every year the growers search for an area with new sand deposits and grow crops on this. This tends to change the course of the river and thus may harm the embankments

M. Difficulties of the service or information as seen by the farmers concerned

None, because this is a farmer innovation used by the same farmers who developed it

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Development of a package of practices for pests and diseases and nutrient management is required to be worked out to support this practice scientifically.

Income of the farmers and landowners outweighs the losses caused to embankments and ecology. There is, however, a good chance to standardize this practice and stabilize the embankments through appropriate mechanization

O. Chances of expanding the application of the improved example

The example has a potential for replication in analogous conditions world wide

P. Related examples found elsewhere in the Province (or in the country for that matter)

The practice is in vogue in river beds of Uttar Pradesh, Punjab and Himachal Pradesh, India

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Yes, the example is already documented in an Indian Council of Agricultural Research, New Delhi, publication "Validation of indigenous technical knowledge in agriculture", Document 3. This is a mission mode project on collection of documentation and validation of indigenous technical knowledge. A study of raising cucurbitaceous crops in sand dunes under water scarcity condition was validated by Dr. Baldeo Singh, Dr. A.D. Munshi, Dr. R.N. Padaria and Dr. Punam Sharma, Division of Agricultural Extension, Indian Agricultural Research Institute, New Delhi. It was concluded that this practice of vegetable growing during off season without irrigation was technically feasible and economically viable

R. Could research assist in improvement of the service/information and how?

An integrated package of practices for pests, diseases and nutrient management is required to be worked out

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

The local adaptive strategies to combat water stress, low temperature, frost and high temperature finds its basis deep into the traditional knowledge and indigenous technologies which have stood the test of the time. This example is an important innovation of the farmers for raising vegetable crops in inhospitable environments

[Original submission edited by Rajendra Prasad and Kees Stigter; version for this book edited by Kees Stigter]

[Original submission obtained third prize in third INSAM contest of 2007]

II.7 *Protocol number 7*

Short name of the example:

Agrometeorological information for the prevention of forest and wildland fires

A. Country/Province where the example was found

Cuba, Villa Clara, Santa Clara

B. Institute providing the example (with address)

Agrometeorology section, Scientific Group, Meteorological Center of Villa Clara, Postal address: Marta Abreu 59, e/Juan Bruno Zayas y Villuendas, Santa Clara, Villa Clara. CUBA. CP: 50100.

In collaboration with Villa Clara Forest Services

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Ismabel María Domínguez Hurtado
(ismabel.dominguez@vcl.insmet.cu; ismabelmaria@yahoo.com; ismabelmaria@gmail.com)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Forest Fires (FF), Agrometeorological Services (AS), DRought (DR), Agrometeorological Indicators (AI), EXtension (EX), Weather Forecasting (for agriculture) (WF), Ecosystems and Natural vegetation (EN)

E. Natural disaster(s) and/or environmental problems to which the example is related

Forest and wildland fires, drought, pollution

F. Way, in which the example was found, defined and collected

From the operational services by the agrometeorological section – Scientific Group – of the Meteorological Center of Villa Clara, in collaboration with local agrometeorological stations

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Plantation forestry and natural formations (for example **cuabales** *and* **charrascales***). Extensive rainfed plantations of sugar cane (***Saccharum** *spp.), grassland*

H. Regions of the county (or counties) where the example can be found

The example can be found in agricultural areas of the central region of the Cuba archipelago, at Villa Clara province

I. Villages where the example can be found

The whole of the municipalities of Villa Clara

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

The most recent data show that as of May 2005, the largest number of fires occurred in the central region of the territory. Particularly, Villa Clara had the highest number of acres planted in areas affected. This contribution, framed within the territorial project CITMA 0615, drew three specific objectives: (i) to characterize the behavior of forest fires in the province, (ii) to apply a risk index adjusted to the characteristics of the area and (iii)to propose a methodology for forecasting wildfires in Villa Clara.

The characterization of fires took place in the province, using information provided by the Villa Clara Forest Services. We selected the following variables: time of occurrence of fire, start and detection time, municipality, city, causes (classified as negligence, intentional, natural or unknown; specifying – where possible for natural causes – origin of those fires: meteorological drought, thunderstorm, other natural probability), the affected area (ha), combustible material (category herbaceous extract, tree extract), type of fire (in category cup, surface, underground or combination of categories), affected species (common and scientific names), age of plantations affected and economic losses estimated.

The approach related data thus obtained with meteorological variables from the weather stations of the Provincial Meteorological Center in Villa Clara, Institute of Meteorology. Three indexes were tested: Nesterov index (modified by the Institute of Forest Investigations of Cuba in 1994), Ångstrom index, and Monte Alegre index, also known as index Osares. The latter was developed for wet ecosystems of southeastern Brazil, but is currently also being applied in some provinces in northern and northeastern Argentina. In the specific case of the capital, Santa Clara, three methods were compared: Nesterov I, Nesterov II and Monte Alegre formula.

A table was designed, initially supported in Microsoft ® Excel, for the computation of the danger, which was replaced by a program in C ++ to facilitate operations. From the information obtained in conjunction with the Villa Clara Forest Services we designed a scheme to facilitate the flow of information between the two institutions.

The procedures described above are carried out both in the meteorological stations and in the provincial office. Subsequently processed as an agrometeorological service, supplemented with information from drought and weather forecasts, it is transmitted from de Meteorological Center (automatically, and in some cases by *phone) to the command post Forest Services in Villa Clara, agricultural enterprises, insurances sectors and government authorities. In order to strengthen the surveillance system at the local level, the weather stations can provide this service to the units closest to the eventual request.*

Validation and effectiveness of the service is evaluated in partnership between forest authorities and the Meteorological Centre. This considers the number of fires detected during the season and agrometeorological conditions provided.

It was noted that the characteristics of forest fires in Villa Clara did not differ significantly from the rest of the country, in addition to corroborating that the influence of extreme temperatures, relative humidity and accumulated rainfall at the beginning of the fires are crucial for their development

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

It achieved a more efficient allocation of resources for fighting forest fires, as well as the location of the same in the areas of greatest risk, with consequent reductions in economic and environmental losses.

From the point of view of farmers, the service has helped to improve the management of resources and the preparation prior to the season of greatest risk of fires

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

- *Difficulties in telecommunications with Villa Clara Forest Services, mainly caused by the constraints in the availability of technical resources.*
- *Low availability of personnel dedicated to fires surveillance in areas of difficult access, which leads to limitations in detecting outbreaks.*
- *Difficult access to some areas with fire hazard.*

M. Difficulties of the service or information as seen by the farmers concerned

Difficulties in the transmission of forecasts (short term), especially in mountainous areas, where communications are difficult because of limitations on equipment and connectivity

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

The results expected from one of the research projects underway, developed by the Provincial Meteorological Center in Villa Clara, are supposed to expand the service. In this case completed with similar information regarding agricultural drought (more information can be found in section R of this protocol).

In addition, the methodology aims to provide forecasting of air quality, essentially taking into account pollution caused by emission products of forest fires

O. Chances of expanding the application of the improved example

There is ample scope for extension and generalization of our experience. In fact, in all comparable locations the system can be used. The main constraint is the availability and representativeness of meteorological data. Consideration should be given in the widespread service to the validity of the indices used. Basically, the Nesterov index has been a successful yardstick, but it requires a pilot study for its introduction

P. Related examples found elsewhere in the Country (or Countries for that matter)

In many countries there are experiences in monitoring forest fires through the use of index-based meteorological risk variables (fire ecology), but many of them operate at the national level, not locally. In our country there are other provinces that have agrometeorological information systems for the prevention of forest fires, but they do not have a design similar to our proposal. We do not have information on the use of similar forms of warning and diffusion of agrometeorological information through the channels described

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Yes, results described are part of a regional research and development project (R & D) funded for the environmental agenda of the Ministry of Science, Technology and Environment (CITMA, in Spanish) of the Republic of Cuba. The experiences of this research were accepted:

- *Vth International Conference on Development and the Environment (Ist International Symposium on Watershed Management), Ciudad de La Habana*.
- *XVth International Congress of Meteorology (Iberian and Latin American Federation of Societies of Meteorology, Mexico (FLISMET, by its abbreviations in Spanish)), Mexico*.
- *International Congress on Disaster, Ciudad de La Habana*.

In addition, some results were part of a thesis option Masters degree in Forestry Science of a specialist of Villa Clara Forest Services.

Also, the experiences have been published in:

- *Proposal of a daily meteorological index of forest fire danger for the municipality Santa Clara. Memories IV Forestry Congress (CUBA). May 14–17, 2007. ISBN: 978-959-282-048-7*

- *Proposal of a daily meteorological index of danger to elevate the effectiveness of the prevention and extinction of forest fires in Santa Clara. Revista Forestal Baracoa 25(2):25–33. ISSN: 0138-6441*

R. Could research assist in improvement of the service/information and how?

Yes, of course. As is known, drought (meteorological, agricultural) has a close connection with the occurrence and extent of forest fires. Therefore, we plan incorporating other indices, associated with drought, to improve the effectiveness of agrometeorological forecasting of hazardous conditions.

Recently two projects were approved that contribute directly to the improvement of services. The first is on technological development ("Renewing and strengthening of the agrometeorological network in Villa Clara") (2008–2013), financed by the regional program of the provincial delegation of the Ministry of Science, Technology and Environment in Villa Clara. This aims to reduce the scale of work by the inclusion of "volunteers", previously trained; together with data from two new automatic stations (including new variables such as radiation). The second project, in this case financed by the National Environment Fund of the Republic of Cuba, is one through which the Forest Service headquarters in Villa Clara refines the monitoring strategy at the local level.

Moreover, the service is part of strategic actions in the implementation of the Operative Program 15 "Sustainable Land Management" in Guamuhaya, with a view to reconcile the commitments made by the country with the GEF/UNDP and the interests of the National Programs for Development, Management and Environmental Protection

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

Undoubtedly, the agrometeorological service is a basic tool for combating forest fires. But only through a comprehensive assessment of the problem and by using the experience of previous campaigns, has it been possible to determine more effectively the location of the areas where the greatest risks occur; thereby reducing the threat of these natural phenomena by appropriate action.

The agrometeorological information to combat forest fires has become an indispensable tool for the work of the Forest Service in Villa Clara. This service has helped establish very close working ties with the institutions responsible for the protection of forests. But it has also been extended to the government units responsible for environmental management, specifically those responsible for the conservation of protected areas in the province, watershed management and reforestation

[Original submission edited by Ismabel María Domínguez Hurtado and Kees Stigter; version for this book edited by Kees Stigter]

[Original submission obtained fourth honorary mention in the third INSAM contest of 2007]

II.8 <u>*Protocol number 8*</u>

Short name of the example:

Furrow planting and ridge covering with plastic for drought relief in semi-arid regions

A. Country/Province where the example was found

China, Shanxi Province

B. Institute providing the example (with address)

Meteorological Institute of Hebei Province (Provincial Meteorological Administration), No.178, Tiyu Nandajie, Shijiazhuang, 050021 China P.R.

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Chunqiang LI (chunql@sohu.com; chunqiangl@gmail.com)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

DRought (DR), Agrometeorological Services (AS), Operational Agrometeorology (OA)

E. Natural disaster(s) and/or environmental problems to which the example is related

Insufficient rainfall, Agricultural drought, Water resources shortage

F. Way, in which the example was found, defined and collected

The example was found applied by farmers in the field in the south of Shanxi Province. It was better understood partly from quantitative research conducted at Jishan county, in the south of Shanxi Province, partly from a book that introduces techniques and knowledge of agrometeorological hazards in China

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Rainfed cropping systems:

- *winter wheat and cotton (with one harvest of each in 1 year)*
- *sequential winter wheat-corn (in general, there are three harvests in 2 years, i.e. two times for corn and one time for winter wheat)*

H. Regions of the county (or counties) where the example can be found

South and middle part of Shanxi Province, Gansu Province, West China

I. Villages where the example can be found

Many in the provinces mentioned

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

In the areas concerned, ridging is applied and these ridges are covered with plastic film (Colour: white; Type: PC, Polyvinyl Chloride, or PE, Polyethylene; it was not biodegradable in the 1980s and 1990s), while planting takes place in the furrows created.

By comparison with winter wheat growing in level soil, it was found that soil water content about doubled in the furrows and was only 10–20% in the ridges after a small or medium rainfall. From the literature, at 0–40 cm soil moisture was increased 3% and at 40 cm it was increased about 10% compared to level soil cropping (i.e. no ridge and furrow).

Overall, there is of course no difference in precipitation received above the surfaces of ridges, furrows and level soils, but a rainfall reallocation is taking place between the plastic covered ridges and the furrows. The water flows from the ridges to the furrows. And the result then is that much water is stored in the furrows, e.g. a 20 mm rainfall per unit of surface is equivalent to a 40–50 mm falling on the furrows. This enhances the plant available soil moisture. This is a form of water harvesting on a small scale but over a large surface.

In addition, soil evaporation was reduced by film cover and this has a positive effect on water conditions, because more water remains available to the plants.

The average daily mean soil temperature increased because of the film cover over the ridge, also in the furrow, at different depths. At 5 cm soil depth, for example, the temperature was raised in the order of 2° in the ridge and more than 0.5 a degree in the furrow, respectively. Before the wheat stop growth in the winter, soil temperature of the furrow at 10 and 15 cm was increased 0.6–0.7 and 0.7–0.8° respectively, compared to level soil

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

Through many years of agrometeorological extension service, this method gives better results. These include higher efficiency in the use of rainfall, therefore saving water resources, reducing production costs and enhancing crop yields

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

From the experience of the extension in Shanxi Province, for this drought mitigation technology, there are no specific difficulties for farmers to understand and accept it

M. Difficulties of the service or information as seen by the farmers concerned

No such difficulties are to be expected as long as the extension services get convinced

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Water is a serious problem for agricultural production in North and Northwest China. Winter wheat is planted in the dry season of the year, so it is a very obvious problem for high yield during that period. Integrated drought mitigation measures are needed, including this example and other kinds of rainfall harvesting that improve crop water use efficiency in these regions. Weather forecast information is also expected by farmers

O. Chances of expanding the application of the improved example

Depending on where water resources shortages occur. This agrometeorological service can also be used as an adaptation measure to climate change, where temperatures increase and rainfall decreases. Institutionalization of such agrometeorological services through establishment and training from the extension services or other intermediaries are needed for such expansions

P. Related examples found elsewhere in the Province (or in the country for that matter)

It has these days spread to Hebei Province, with some integration changes with the natural environment

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Yes, part of the research papers already appeared in the Chinese Journal of Agricultural Meteorology, as well as in a book about dry-land farming in China

R. Could research assist in improvement of the service/information and how?

New research can assist in the expanded and integrated use of these technologies in different regions according to the local natural conditions, such as climate, soil, *topography and crop planting methods. From the view point of a rational utilization of natural water resources, weather and climate information should be available and understood as a priority by the extension services concerned. This would mean that these extension services should also be trained in the establishment and validation of such agrometeorological services*

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

No

[Original submission edited by Li Chunqiang and Kees Stigter; version for this book edited by Kees Stigter]

[Original submission obtained fifth honorary mention in third INSAM contest of 2007]

II.9 <u>*Protocol number 9*</u>

Short name of the example:

Design of on-station alley cropping trials on flat land in the semi-arid tropics

A. Country/Province where the example was found

Kenya, Machakos area

B. Institute providing the example (with address)

University of Nairobi, Department of Geography, P.O. Box 30197, Nairobi, Kenya

C. Researcher(s) that collected/described this example (with their e-mail addresses)

David N. Mungai (dmungai@uonbi.ac.ke), C.J. Stigter (cjstigter@usa.net), C.L. Coulson (candp@coulson96.karoo.co.uk), J.K. Ng'ang'a (jnganga@uonbi.ac.ke)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agro-Forestry (AF), Agrometeorological Services (AS), Crop Micrometeorology (CM), Climate Variability (CV), DRought (DR), Education and Training (ET), EXtension (EX), Operational Agrometeorology (OA), RIsk in weather and climate (RI), User's Needs in agrometeorology (UN)

E. Natural disaster(s) and/or environmental problems to which the example is related

Drought and erratic rainfall, Low and decreasing soil fertility as well as low organic matter contents

F. Way, in which the example was found, defined and collected

On-station experiments were necessary to determine the feasibility of alley cropping without the use of fertilizers on flat land in semi-arid Kenya, because on farm experiments were considered too risky at the time (late 1980s). It was carried out by Ph.D.- and supportive M.Sc.-research with an advisory role of the International Council for Research in Agro Forestry (ICRAF, now World Agroforestry Centre), Nairobi

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Small rainfed Low External Input Agriculture monocropping maize farms

H. Regions of the county (or counties) where the example can be found

Area representative for eastern and central lowland Kenya

I. Villages where the example can be found

Not applicable because on-station

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

Agroforestry gained attention because of its perceived potential to sustainably enhance agricultural production under low external input conditions and to offer other benefits to resource poor farmers. Alley cropping (or hedge row intercropping) as a designed agroforestry system evolved in the humid tropics to replace shifting cultivation. It involves the intercropping of annual crops in alleys formed by hedgerows of perennial species. The hedge rows are periodically lopped to provide mulch and to ameliorate the above ground microclimate of the companion crops.

Alley cropping belongs to a large range of traditional and more recent attempts to make use of benefits of microclimate manipulation in intercropping. The quantitative assessment of the microclimatic effects of hedgerows and mulching in an alley cropping system is important for evaluating the potentials of this cropping combination. It is even more important for semi-arid environments, where the experience is more limited. However, such attempts are rare, partly due to lack of quantification in the traditional as well as the local scientific cultures and partly due to lack of established sampling methodologies to apply in such systems.

In the alley cropping system studied, every fourth row of maize was replaced by a row of Cassia trees, and loppings were incorporated into the soil at the beginning of each maize growing season. In this kind of replacement agroforestry, we found that there is more difference between yields in agroforestry systems and the monocropping controls at higher amounts of rainfall and with better rainfall distributions. Our work on flat land proved that it was difficult to increase crop yields considerably by alley cropping in the semi-arid tropics in other than appreciably above average rainfall years with a beneficial rainfall distribution. This is a fortiori true for additive agroforestry systems. The competitive effects of hedgerows on crops appreciably decrease the benefits gained from the additional fertilizing from the loppings. There is even a relatively low rainfall amount below which the controls do often better.

The age of the agroforestry system also plays a role in these matters of competition, but influenced by the pruning regime applied to obtain the mulch for incorporation into the soil or distribution over the soil. In alley cropping in semi-arid areas root pruning can not be exercised because this would limit even more the biomass production necessary for obtaining the mulch to be applied. In intercropping with hedges and scattered trees as well as with shelterbelts, where mulch use of loppings *is not applied, tree root pruning successfully limits the competition of the trees with adjacent crops, particularly when the trees get older. However, tree growth is influenced by root pruning, depending on the pruning system applied and the rooting patterns of trees.*

Ever since the late 1980s and early 1990s it is clear that adoption of such systems by farmers is much lower than expected and our early work made clear why farmers have such negative feelings on alley cropping. Low biomass production, insufficiently improving soil conditions, and high competition for resources between trees and crops are the main causes. Farmers are thus advised not to apply such systems on flat land in semi-arid conditions. That was the agrometeorological service delivered by this research in the late 1980s and disseminated through ICRAF channels

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

None on this flat low fertility land

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

Our early work on flat land showed very clearly that agroforestry systems must at least provide strong physical protection of crops (for example from wind, sometimes from pests) and/or soils (for example from wind or high radiation) and/or have a very strong economic incentive to be of any interest to farmers

There has been a belief that trees and crops take their resources from different soil horizons, but it appears that in cases like ours there remains a lot of root overlap in many zones, making the existing competition understandable. In our research with Cassia (Senna) siamea trees, competition was stronger in the middle of the rows compared to closer to the trees. This could only be understood from higher overlap of roots in those areas, which we proved to exist from laborious quantification of root length densities.

The influence of trees on microclimate, particularly radiation and wind, so also soil and air temperature microclimate, heavily depends on heights and distribution patterns of the trees. In our alley cropping examples dealt with here, the trees remained low, bush like, and their influence on radiation, wind and temperature in the rows where the crops were grown remained quite limited to the tree/crop interface and the earlier growth stages. In fact below surface soil conditions were influenced most by the presence of the alley trees. As soon as we work with hedges, shelterbelts and/or scattered trees of sufficient height to considerably influence the wind regime, also the other microclimatic factors are more seriously influenced. This includes rainfall redistribution after interception by the trees

M. Difficulties of the service or information as seen by the farmers concerned

The use of additional amounts of artificial fertilizers reduces the competition between the trees and the crops. However, most farmers interested in alley cropping cannot economically afford such additions. Other factors that have to be taken into account in introducing (contour) hedgerow intercropping are (i) high and inflexible labour requirements (for pruning), (ii) secure long-term access to land, (iii) gender issues limiting access to land and rights to grow trees for women, as well as (iv) compatibility of trees and crops and the economy of tree products

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Soil and water conservation have now generally been recognized as one of the main clear benefits of hedgerows on sloping land with an acceptable level of fertility. The soil conservation appears of most importance. Our rigorous quantitative approach made it possible to well determine advantages and disadvantages of these agroforestry systems. For a full understanding of farmer adoption or the lack of it, a range of other factors have to be considered

O. Chances of expanding the application of the improved example

Not advisable on flat land

P. Related examples found elsewhere in the Province (or in the country for that matter)

Not applicable because on-station work

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

A big advantage of our approach was the for agroforestry research unusual rigour of our agrometeorological quantification (see Chap. IV.9 on Field quantification). This applied to radiation, in the form of shade quantification and understanding of competition for radiation, of soil temperature (also as an indicator of shade), of soil moisture and of root length density, both particularly important as indicators of time and place of actual competition. We also additionally measured, for limited periods, rates of photosynthesis and transpiration rates.

A most successful innovation was the use of soil temperature for following slow moving shading patterns. Successful tracing of measuring errors did take place in the investigation of the influence of the direction of mounting for solar tubes, integrating solar radiation interception. The use of simple equipment for measuring soil moisture showed the potential and the limitations of such multi-point measuring methods.

Many research publications of the team, including the ones here not mentioned on microclimate quantification under these conditions (see Chap. IV.9), do exist. For the immediate importance of our approach the following publications should be explicitly mentioned here (in chronological order):

Mungai DN, Coulson CL, Stigter CJ (1990) Economic considerations of alley cropping for food production in semi-arid areas. In: Prinsley RT (ed) Agroforestry for sustainable production: Economic implications. Commonwealth Science Council, London, pp 311–321

Mungai DN (1995) A micrometeorological approach to understanding maize yield performance in alley cropping in the semi-arid areas of Machakos District, Kenya. In: Stigter CJ, Wang'ati FJ, Ng'ang'a JK, Mungai DN (eds) The TTMI-project and the "Picnic"-model: an internal evaluation of approaches and results and of prospects for TTMI-Units. Wageningen Agricultural University, Netherlands, pp 111–123

Mungai DN, Stigter CJ, Ng'ang'a JK, Coulson CL (1996) New approach in research education to solve problems of dryland farming in Africa. Arid Soil Res Rehabil 10:169–177

Stigter CJ, Van den Bor W, Daane JRV, Adam HS, Mohammed AE, Ng'ang'a JK, Mungai DN (1998) The "picnic" model for research training at African Universities: evaluation and preliminary comparison. J Agric Educ Ext 5:23–38

Mungai DN, Coulson CL, Stigter CJ, Ng'ang'a JK, Mugendi DN (2001) Phenotypic nutrient up-take differences in an alley cropping system in semi-arid Machakos, Kenya. J Environ Sci (China) 13:164–169

Mungai DN, Stigter CJ, Coulson CL, Ng'ang'a JK, Netondo GWS, Umaya GO (2001) Understanding yields in alley cropping maize (Zea Mays L.) and Cassia siamea (Lam.) under semi-arid conditions in Machakos, Eastern Kenya. J Environ Sci (China) 13:291–298

R. Could research assist in improvement of the service/information and how?

Not anymore

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

This has been an example where on-station research indeed showed that on-farm research would have been too risky to obtain this agrometeorological service of negatively advising, through ICRAF, on using alley cropping on flat land in semi-arid areas

[Original submission in 2007 edited by Kees Stigter; version for this book edited by Kees Stigter]

[This is an example of an agrometeorological service with negative results on flat lands. The design appeared to be not recommendable for semi-arid regions]

II.10 *Protocol number 10*

Short name of example:

Early snow melting through surface spread of soil material

A. Country/province where example was found

Himachal Pradesh, District Lahaul and Spiti, India

B. Institute providing the example (with address)

Dr. Rajendra Prasad, Agrometeorologist, Department of Agronomy, Agrometeorology section CSK Himachal Pradesh Agricultural University, Palampur 176 062, Himachal Pradesh, India; Dr. Vijay Singh Thakur, Associate Director, Highland Agricultural Research and Extension Centre, Kukumseri – 175 142 Lahaul Spiti, Himachal Pradesh, India

C. Researchers that collected/described this example (with the e-mail addresses)

Dr. Rajendra Prasad (agron@hillagric.ernet.in; rprasad57@gmail.com),
Dr.Vijay Singh Thakur (rprasad57@rediffmail.com)

D. Field(s) of Agrometeorology to which the example belongs:

[Use the fields of interest defined for registration of members of INSAM]

Micrometeorology in General (MG)

E. Natural disasters (s) and/or environmental problems to which the example is related

Prevailing low temperatures during March and April do not allow the early melt of snow and so, the fields are not free from snow. This hinders the field preparation for the sowing of peas, potato, hops, vegetables, barley and buckwheat

F. Way, in which the example was found, defined and collected

This is an age old practice followed since the Epic Mahabharata in Lahaul and Spiti district of Himachal Pradesh. While working in Spiti valley, the authors found that the farmers utilized this practice (of spreading the soil on snow) for early melt of snow. This helps in early vacation of the fields for land preparation for the sowing of different crops

G. Farming system(s) in which the agrometeorological service is applied or to whom the agrometeorological service is provided for actual use

The climate of Lahaul and Spiti is most suitable for production of temperate fruits and vegetables of high quality. Only one crop out of peas, potato, hops, vegetables, barley and buckwheat is raised in one season/year. "Churu", "Yak", cattle, sheep and goats are the main animals reared. By following this practice of early snow melting, two crops are possible, one main season crop and another short duration crop

H. Region of the country (countries), where the example can be found

Lahaul and Spiti, Chamba and Kinnaur districts of Himachal Pradesh, India

I. Villages where the examples can be found

Pattan, Tinnan, Mayar and Gahar valleys of Lahaul, Pin, Sagnam, Losar and Tabo valleys of Spiti, Sangla valley of Kinnaur and Bharmour areas in Chamba district of Himachal Pradesh, India

J. Describe the good example of the operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problems(s) concerned

*It is well established that areas lying between 2,500 and 3,500 m above mean sea level remain snow bound from October to April. Extremely low temperature***s** *restrict the length of growing season of different field crops like peas, potato, hops, vegetables, barley and buckwheat.*

To prolong the length of the growing season, it is essential to enhance the melting of snow. This problem is tackled by spreading the fine textured soil on the snow-covered fields, where sowing is to be undertaken during late March and early April.

Darker soil absorbs more heat than white snow and this heat is partly conducted downward, causing faster melting of the snow by about 8–30 days, depending upon amount of snowfall received during the season. This helps in early sowing of the crop(s) and enables the sowing of a second short duration crop like buckwheat or rapeseed/mustard.

This is again an example of attempts to collect traditional techniques of micro-climate improvement for a better understanding and for possible transfer to other places, eventually in a modified form. This case is a marvellous example of traditional "mulching", changing the albedo (surface reflection) of the surface.

It is an agrometeorological service worth putting into practice and suitable for recommendation for early melt of snow in all snow bound areas. Perhaps it would also help on frozen soils with light surface colors.

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increases in income due to the services or information

The economical benefit is still required to be assessed and documented. However, a quick estimate gives for peas at least Rs 15,000–20,000 ha^{-1} *as an additional income if snowmelt is induced 20 days earlier*

L. Difficulties encountered in introduction and use of good example of agrometeorological services or information

Snowfall episodes are also on decline, due to global warming, while, like rain, snow is also a variable weather parameter with respect to time and space. One can, however, expect a copious snowfall every now and then in snow bound areas during winter. This example always holds good for capitalizing on the early melt of snow

M. Difficulties of the service or information as seen by the farmers concerned

The example embraces traditional scientific wisdom and there appears in first instance little scope for further improvement in this practice but to determine this, experiments would have to be designed

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

No improvements are envisaged, but in the introduction to this Part II it is indicated how such practices can be used for experimental and theoretical developments with mulches

O. Chances of expanding the application of the improved example

The example can be replicated in any other analogous conditions

P. Related examples found elsewhere in the Province (or in the country for that matter)

There is no evidence to show that this example is practised elsewhere in the province except the valleys/areas mentioned above

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Yes, the example is already documented in an Indian Council of Agricultural Research, New Delhi publication " Validation of Indigenous Technical Knowledge in Agriculture" Document 3. This is a mission mode project on collection of documentation and validation of indigenous technical knowledge. A comparative study for willow ash and fine textured soil with respect to their amount and efficacy was undertaken by Dr. M.L. Parmar and Sh. Ajay Thakur, Department of Chemistry, Himachal Pradesh University, Shimla 171 005. The practice was also presented by

Dr Vijay Singh Thakur, one of the authors of this example, in a National Seminar on Indigenous Technologies for Sustainable Agriculture, New Delhi, during March 23–25, 2007

R. Could research assist in improvement of the service/information and how?

Research as mentioned under N. and Q. could usefully be undertaken

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

The local adaptive strategies to induce early melt of snow find their basis deep into the traditional knowledge and indigenous technologies, which have stood the test of the time. It is helpful to be able to take on a second short duration crop in snow bound areas

[Original submission edited by Rajendra Prasad and Kees Stigter; version for this book edited by Kees Stigter]

[See the introduction to Part II for developments in Dar es Slaam in the late 1970s and early 1980s that delivered a physical theory to understand traditional knowledge as reported here]

II.11 *Protocol number 11*

Short name of example:

Water use and water waste under traditional and non-traditional irrigation practices

A. Country/Province where the example was found

Sudan, Central Sudan, Gezira Irrigation Scheme

B. Institute providing the example (with address)

Hydraulics Research Station (HRS), Ministry of Irrigation, Nile Street, P.O. Box 318, Wad Medani, Sudan

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Ahmed A. Ibrahim (dit Kabo) (hrs_sudan@hotmail.com), C.J. Stigter (cjstigter@usa.net), H.S. Adam (hsadam2002@yahoo.com), A.M. Adeeb

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agro-Hydrology (AH), Agrometeorological Services (AS), EXtension (EX), Operational Agrometeorology (OA), Policy Matters (PM)

E. Natural disaster(s) and/or environmental problems to which the example is related

Water waste in modern irrigation management, low fertilizer use, standing water due to low attendance of watering

F. Way, in which the example was found, defined and collected

In the Gezira irrigation scheme, serious symptoms of water waste have been identified in the last two decades with modern irrigation approaches with less field attendance, especially in sorghum and groundnut fields. A serious debate among authorities on return to traditional irrigation attendance and methods or other possible solutions needed quantification of the wastes concerned. On their request a quantitative study was undertaken to this end that also should suggest ways to improve on the situation that are compatible with the local socio-economics of the use of sharecroppers

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Tenants growing rotations of irrigated sorghum and groundnut (as private crops), cotton and wheat (to be sold to the government) on heavy clay soils

H. Regions of the county (or counties) where the example can be found

All irrigation schemes where watering with less attendance, by sharecroppers or otherwise in the watering of crops, has developed

I. Villages where the example can be found

The on-farm research was conducted near Hamza minor canal of the Tibub Block in the Central Division of the Gezira scheme

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

Tenants are dissatisfied with overall maintenance of the scheme. Authorities (Ministry of Irrigation, Sudan Gezira Board) are dissatisfied with tenants' water use. These authorities are of the opinion that the farmers are wasting water by the unattended continuous (day and night) irrigation method they have evolved, especially for their private crops dura (sorghum) and groundnuts. There is the belief that remarkable savings in water would be obtained if the tenants would go back to the traditional night storage system, in which rather laborious and well-attended daytime application of water is practised.

To possibly strengthen but at least verify the arguments of those who want to change the situation, it was thought useful to accurately quantify the problems under participatory on-farm conditions. Quantitative agrometeorology has sufficiently strong methods to be able to do so. The study has revealed wastage of irrigation water in both, traditional and more recent irrigation methods, but at different rates and also differently for each crop. In the attended fields, the average seasonal overirrigation, which is the difference between average application depth Q and average soil moisture deficit SWD, was observed to range between 0.4 and 1.5 of SWD (0.3 and 0.6 of Q) and the corresponding values in the unattended field were 0.6 and 3.2 of SWD (0.4 and 0.8 of Q). The farm water application efficiency values were 50% of those shown in the literature and this also indicates that much of the water application in the Gezira is not being economically invested, due to lack of other inputs, mainly nutrients.

It was calculated that 570 mm was likely to be a good first approximation of the minimum requirements for groundnut in the Gezira farming system under attended irrigation. Higher water applications reduce groundnut yields. For the two sorghum varieties, Fitareeta and Hageen, of which the latter needs one irrigation more, these values appear 470 and 560 mm respectively. These values are for the present field topography and other farm management conditions. These values also still include a too high soil moisture value at maturity, which was estimated as 50–80 mm *readily available water in this case. Because no surface runoff occurs from the fields, the Gezira free surface evaporation losses, which for the drier year amounted to the highest values (170–230 mm) for groundnut in the attended and the unattended fields respectively, that are 30–50% of the above minimum requirements of the two crops, will remain the main type of non-productive water reaching the present fields.*

The results confirm that irrigation water is wasted in both application methods, but at different rates and differently for each crop. The waste was higher in unattended irrigation of both dura and groundnut, and the waste was larger on groundnuts. It had also larger consequences because groundnut yields drop with excess water applied. Even much of the consumptive use is economically ill invested in non fertilized dura, because with higher inputs the same amounts of water would give higher returns. The application differences were mainly due to the watering methods, causing different amounts of standing water, and the methods of determining the moment of irrigation. Another type of non-productive water is the readily available water retained in the soil profile at the end of each growing season.

More efficient water and farm management (e.g. weeding) in the scheme is crucial for obtaining the same or somewhat higher yields with other external inputs remaining at the present low level. The most important measure in this respect would be to adopt a land levelling program to the practical limits possible and to apply partly or fully attended watering on small areas, as was recommended in the traditional night storage system. Minimum practical standing water in the furrows during and immediately after each irrigation must be targeted. Economic measures related to the payment and prize of irrigation water should also be taken

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

The importance of preventing waste of water may be stressed by noting that Sudan is approaching the limit of depleting its quota of Nile water as determined under the agreements with Egypt. The 0.9 million ha of the Gezira cum Managil irrigation scheme consumes about one third of these quota. In the context of this work, the late M.F. Sadek et al. determined that the present evaporation losses of Lake Nasser, the reservoir of the High Aswan Dam, in Egypt, is very likely close to 20% less than presently assumed. This shows the necessity of thorough quantification of all factors involved.

These quantitative on-farm water waste determinations belong to the innovative results of this research. Knowing now much more precisely how large the problem is, and which components it quantitatively has, will contribute much to the arguments of those who want to take the proposed measures

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

From results of a questionnaire prior to our field work, it followed that the tenant farmers in the Gezira scheme evolved their present unattended watering practices of groundnuts and sorghum out of the sheer necessity of engaging sharecroppers. The latter have to leave irrigation unattended because of their own need for additional off-farm employment/income. Also the serious fluctuations of water in the Minor canals, which should basically be used as storage reservoirs for the night, tended to bring farmers to use of water during the night for their private crops, defying the regulations of the strict night storage method, which allows for day time attended watering only

M. Difficulties of the service or information as seen by the farmers concerned

The replies to the questions posed to farmers on water management revealed that at present: (i) the tenants/farmers do not see any sense in attended watering after the first two irrigations; (ii) they normally adjust the opening of their field and feeder channels, so the flow of water, according to the area to be irrigated and their expected time of absence; (iii) this way they relieve themselves from the closely attended watering practice, which was observed to take about 18–24 full working hours per irrigation with normal flows ($\approx 5{,}000\,m^3\,day^{-1}$ *per feeder channel); (iv) many farmers admit the importance of adopting the Night Storage system but they apply the continuous flow method; (v) farmers appear not to understand that most of the standing water evaporates without being used by the crop; (vi) sharecroppers, who are originally from the western states of the Sudan, Chad or Central Africa, lack knowledge in irrigation. But all tenants use sharecroppers in groundnut and sorghum, for several reasons*

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

The main points that should be used in a dialogue between authorities and tenants on the necessary adaptation of present watering methods are that:

(1) irrigation water is limited at local and national levels, yet the present irrigation practices are inefficient. However, only when clear profits or other incentives convince the farmers, water may be more wisely used on-farm. Less waste will help to do away with over-indenting and to maintain uninterruptedly the required commands in the Minor canals, which reduces the total seasonal irrigation time, by increasing Field Outlet Pipes (FOP) discharges where they are too low, and will help to solve the tail end problems;
(2) if the case study reported on is indeed representative, in the order of at least 20–40% on-farm saving in irrigation water will be obtained if more efficient on-farm application methods, such as attended daytime irrigation, are adopted in the scheme. Minimizing the last irrigation may also contribute;
(3) poor on-farm water management can be attributed to (i) the large sizes of land being irrigated at once in unattended watering, when the NS system is

not applied; (ii) the lack of attention for the duration of the within field water flows and (iii) the visual method the farmers use for their irrigation satisfaction. At the highest places of the field parts considered for irrigation at the same time, minimum depths of water are to be used in the furrows, while standing water by the end of the irrigation should be avoided as far as possible. This means separate irrigation of different levels in the field for appropriate periods, as done in the traditional attended irrigation method. Otherwise, occasional precise land levelling is recommended; and

(4) when dealing with a sharecropper, the tenant should be sure that his partner is attending the irrigations and is provided with the means to do so. This leads to lowest possible water costs

O. Chances of expanding the application of the improved example

Results as obtained in this case study will convince authorities to set up larger scale validations and to carry out improvements, e.g. in levelling and maintenance, to decrease impact of factors that influence water use efficiency negatively and to satisfy tenants. In Sudan this may best be set up through farmers' unions and production councils. As long as individual tenants are not yet charged for their actual water use, water waste should be seriously discouraged by allocating quota of water

P. Related examples found elsewhere in the Province (or in the country for that matter)

No other quantitative data are available from other places

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

In this on-farm research, the most rigorously sampled neutron scattering method was used to determine the actual soil water deficits of the two crops. A simple Penman equation was used for approximating reference crop evapotranspiration and evaporation losses from standing water and wet soil surface. An updated approach using the Penman/Monteith equation was additionally applied. The shaded Piche evaporimeter was used to simplify the obtainment of the aerodynamic term of the Penman equation, after local calibration for different seasons and a physical study of the shaded Piche to guarantee an appropriate performance. The most difficult quantification was that of the flows in the field channels (Abu Sittas) by a Vane Flow Meter in concrete tubes as flow guides, which quantified the irrigations on-farm. Publications on these quantifications have appeared and are available. In the context of this protocol form, the following publications are most relevant:

Ibrahim AA (1995) Water use and water waste under traditional and non-traditional irrigation practices in the Gezira Scheme, Sudan. In: Stigter CJ, Wang'ati FJ, Ng'ang'a JK, Mungai DN (eds) The TTMI-project and the "Picnic"-model: an internal evaluation of approaches and results and of prospects for TTMI-Units. Wageningen Agricultural University, Wageningen, pp 165–172

Ibrahim AA, Stigter CJ, Adam HS, Adeeb AM, Fadl OAA (2000) Farmers' practices in on-farm irrigational management in the Gezira scheme, Central Sudan. Rural Environ Eng (Japan) 38:20–29

Ibrahim AA, Stigter CJ, Adam HS, Adeeb AM (2002) Water use efficiency of sorghum and groundnut under traditional and current irrigation in the Gezira scheme, Sudan. Irrig Sci 21:115–125

Stigter CJ, Ibrahim AA, Adam HS (2004) Water waste in traditional and more recently developed on-farm irrigation management in the Gezira Scheme in Central Sudan. Case study of economically beneficial agrometeorological applications and services and of other success stories in agrometeorology for policy matters. In: Baier W (Coord) CAgM Rep 93, WMO/TD 1202, Geneva, pp 48–52

R. Could research assist in improvement of the service/information and how?

Future research should improve knowledge on crop water requirements at different crop stages and demonstrate substantial profits from diminishing water use

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

Sharecroppers prefer to adopt continuous unattended free application of water, because for the private crops dura and groundnut opening of FOPs is uncontrolled by the authorities and they can make use of the irrigation time to work as hired labour in fields of other crops. The above strongly links the necessities of sharecropping and the unattended watering to socio-economic backgrounds. This weakens any assumption that the unattended watering practice is a mere water availability problem

[Original submission in 2007 edited by Kees Stigter; version for this book edited by Kees Stigter]

[This is an agrometeorological service developed for a precise target group of farmers in irrigated agriculture of the Sudan]

II.12 Protocol number 12

Short name of example:

Shelterbelt design for protection of irrigation canals and agricultural land from blown sand encroachment

A. Country/Province where the example was found

Sudan, Central Sudan, Gezira Irrigation Scheme

B. Institute providing the example (with address)

University of Gezira, Department of Natural Resources and Environment, Faculty of Agriculture, P.O. Box 20, Wad Medani, Sudan

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Ahmed Eltayeb Mohammed (V.Chancellor@ous.edu.sd), C.J. Stigter (cjstigter@usa.net); H.S. Adam (hsadam2002@yahoo.com)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agro-Forestry (AF), Agrometeorological Services (AS), Crop Protection (CP), DEsertification (DE), DRought (DR), Natural Disasters (ND), Operational Agrometeorology (OA), Policy Matters (PM), RIsk in weather and climate (RI)

E. Natural disaster(s) and/or environmental problems to which the example is related

Desert encroachment, Drought, Moving sand

F. Way, in which the example was found, defined and collected

A **Eucalyptus microtheca** *shelterbelt, as an agroforestry technique which uses trees to protect land from moving sand encroachment, was planted by the Gezira Board and Forestry Authorities in an attempt to prevent such an invasion of sand. To understand the mechanism by which sand was settled within and in front of the shelterbelt, on their request a quantitative study was undertaken, that also needed to come up with design rules for shelterbelts to most efficiently combat such sand invasions. Such design rules must be considered an agrometeorological service to these authorities and to the farmers whose land got protected*

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

The irrigation canals and fields that needed protection were used for growing rotations of sorghum and groundnut (as private crops), cotton and wheat (to be sold to the government)

H. Regions of the county (or counties) where the example can be found

North-western parts of the Gezira Irrigation Scheme between the Blue and the White Nile south of Khartoum

I. Villages where the example can be found

Sihaimab and neighboring villages

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

A severe form of desertification, that involves sand movement by wind, is caused by serious land degradation resulting from the forced use of already marginal land resources and their subsequent abandonment, aggravated in drought years. On parts of the periphery of the Gezira Irrigation Scheme of 1 million ha, moving sand had already forced tenants to take land out of production. Destruction is caused to the gravity irrigation system through filling of canals or changing the levels of farm land by sand.

Understanding the sand settling mechanisms of the many kilometers of shelterbelt demanded the quantification of air and sand movement at the windward side of the belt for the season in which the sand moved towards the belt. Under the conditions of maximum sand deposition within the shelterbelts, in the first 10 m near the edge, of about 20 cm year^{-1}*, the front trees survived the sand deposition. Apparently root development was such that the irrigation water kept reaching the roots of these front trees. Sand with more than 2.5 m height was found till about 30 m within the belt, that was made up of staggered Eucalyptus trees of less than 7 m, spaced at 3 m distances. It was estimated that 20–30 m would have been sufficient for the width of the belt in these early years, but wider belts gave more storage space for immobilized accumulating sand*

Our results and existing literature on air movement around shelterbelts were used to indeed develop design rules for shelterbelts for sand encroachment protection. In these rules, composition and geometry of such belts were discussed as to length, width, height, permeability, direction, openings and species. Separate consideration was given to advice on trees to be used in such shelterbelt designs. Growth rate, life span and drought tolerance, heat, pests and diseases, grazing, sand blast and sand *deposition were mentioned. Canopy geometry and byproducts were considered with respect to air flow and economy.*

It was proposed that dense shrubs in the front row(s), followed by tall strong trees, would do best from the windward wind reduction point of view. Some physical land treatments were suggested at the windward side of the belt, to trap some of the encroaching sand and hence increasing the life span of the belt. Some of these design recommendations, that were offered as agrometeorological service, were subsequently used in substantial belt extensions by the Authorities. These extensions for the time being successfully protect endangered parts of the Gezira scheme. It is now proposed that the same design be used for the White Nile Sugar Scheme (west of the Gezira Scheme and east of the White Nile) that is under execution in the same affected area

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

Irrigation canals could again be restored for carrying water and abandoned fields could again be taken into production, while other parts of the Gezira scheme were protected from the beginning

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

The use of such shelterbelts nevertheless demands for concern about lasting sand deposition that can only be prevented if sand can be deposited/stored in the primary or secondary source areas. In a more recent development, the very poor local population living at the periphery of the belts developed **Acacia tortilis** *plantings that, with controlled grazing, now protect, again for the time being, parts of the original belts. They succeed in settling the wind driven sand with these plantings in parts of the secondary source area near to the Sihaimab belts*

M. Difficulties of the service or information as seen by the farmers concerned

See above under L

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Sand settlement in the source areas is necessary for long term protection. Low and to a certain extent medium permeability, as well as the formation of clusters, enhance sand trapping at all sides of scattered trees and grasses, rather independent of wind direction. Scattered trees and grasses of the right kinds, densities and permeabilities have beneficial influence on wind by modifying flows in such a way that the flow *capacities to carry saltating and creeping soil particles are sufficiently reduced. However, such re-vegetation has to occur over large areas*

O. Chances of expanding the application of the improved example

Very good chances wherever the problem occurs near the Gezira Scheme, as it is now proposed for the White Nile Sugar Scheme mentioned above

P. Related examples found elsewhere in the Province (or in the country for that matter)

Not applicable

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

A list of research publications is available. The more pertinent ones in relation to the above are:

Mohammed AE, Stigter CJ, Adam HS (1995a) Moving sand and its consequences in and near a severely desertified environment and a protective shelterbelt. Arid Soil Res Rehabil 9:423–435

Mohammed AE, Stigter CJ, Adam HS (1995b) Holding back the desert: a eucalyptus shelterbelt in central Sudan. Agrofor Today 7(1):4–6

Mohammed AE, Stigter CJ, Adam HS (1996) On shelterbelt design for combating sand invasion. Agric Ecosyst Environ 57:81–90

Mohammed AE, Stigter CJ, Adam HS (1999) Wind regimes windward of a shelterbelt protecting gravity irrigated crop land from moving sand in the Gezira Scheme (Sudan). Theor Appl Clim 62:221–231

Stigter CJ, Mohammed AE, Al-Amin NKN, Onyewotu LOZ, Oteng'i SBB, Kainkwa RMR (2002) Agroforestry solutions to some African wind problems. J Wind Eng Ind Aerodyn 90:1101–1114

Stigter CJ, Mohammed AE, Al-Amin NKN (2004) Use and suitable designs of shelterbelts and scattered trees as well as grasses for protecting agricultural production and infrastructure from wind driven sand encroachment and expanding desertification. Case study of economically beneficial agrometeorological applications & services and of other success stories in agrometeorology for policy matters. In: Baier W(Coord) CAgM Rep. 93, WMO/TD 1202, Geneva, pp 36–39

R. Could research assist in improvement of the service/information and how?

Yes, concerning large scale revegetation of source areas, including the use of airplanes for seeding from the air

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

The kind of design work on holding back the desert, reported here as an agrometeorological service, could also have been carried out on desertification issues that are *at the basis of the resource wars that sparked off many of the civil war situations that occurred and are occurring in Sudan. Appropriate international funding of such work should have started in the 1960s and the 1970s, 30–40 years ago, but was refused even 10 years ago for example by ISNAR*

[Original submission edited by Kees Stigter and Ahmed Eltayeb Mohammed; version for this book edited by Kees Stigter]

[Original submission obtained first prize in second INSAM contest of 2006]

II.13 *Protocol number 13*

Short name of example:

Design of improved underground storage pits (matmura) for sorghum in cracking clays

A. Country/Province where the example was found

Sudan, Sennar Province

B. Institute providing the example (with address)

University of Gezira, Department of Natural Resources and Environment, Faculty of Agriculture, P.O. Box 20, Wad Medani, Sudan

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Ahmed el-Tayeb Abdalla (dratabdalla@yahoo.com), C.J. Stigter (cjstigter@usa.net), M.C. Gough (mcgough@ntlworld.com), Nageeb Ibrahim Bakheit (nagibrahim@hotmail.com)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agro-Climatology (AC), Agrometeorological Services (AS), EXtension (EX), Grain Storage microclimate (GS), Operational Agrometeorology (OA), User's Needs in agrometeorology (UN)

E. Natural disaster(s) and/or environmental problems to which the example is related

Drought, Flooding during showers, Cracks in clay soil

F. Way, in which the example was found, defined and collected

Ph.D.- and supportive M.Sc.-research at the University of Gezira, with a set-up based on local socio-economic surveys and local innovations identified. Request from Government to look into possibilities for increased lengths of times of traditional underground storage of sorghum (dura) grain in small pits

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Rainfed sorghum monocropping, staggered in place and time, for subsistence farming and local markets

H. Regions of the county (or counties) where the example can be found

Various African countries and various regions in the Sudan

I. Villages where the example can be found

Research was done in Sennar Province villages Fangoga el Jabal (cracking clay soil), Awlad Mahala (non-cracking clay soil) and Kumur el Nair (sandy soil)

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

Traditionally, the so called matmuras are dug in black cotton soil where preferably there are no cracks or sandy or chalk deposits. Cylindrical in shape, they hold from 2 to more than 150 t of sorghum grain, but they are always dug in the same way. Subsistence farmers generally use sizes for 2–5 t, farmers also growing for local markets use sizes for 5–10 t, traders use sizes for 10–50 t, although occasionally larger sizes do occur. A traditional matmura will protect grain for only up to a month if the newly dug pit is exposed to the sun for only a day. Humidity and radiation intensity are important factors in drying pits; the longer they are dried in optimal climate conditions, the longer they are able to store grain effectively.

In the central clay plain of the Sudan, traditional subsistence farmers and small farmers that also produce for the local market want to keep the region near self-sufficiency. They combine annual production of sorghum with underground pit storage of part of the harvest. With increasing climate variability this food security is coming more and more under pressure. This encouraged farmers in Central Sudan to experiment with possible improvements of their traditional underground storage pits for sorghum grain. These innovations were quantified in our research.

Microclimate measurements of grain moisture contents, grain temperatures and pit air carbon dioxide contents, in experimental pits, made it possible, as an agrometeorological service, to test and improve their designs. Derived farmer innovations of using shallower pits (50 cm in the experiments), applying chaff linings at bottom and sides of these shallow pits (of at least 25 cm before compression by the grain filling in the experiments), made safe storage possible during at least two consecutive bad rainy seasons. Wide above surface caps (1 m beyond the pit diameter all around in the experiments), to diminish chances of surface cracks leading water to the grain, were a necessary condition added by the research experience

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

Local farmers generally have very little capital, but they do have access to the resources necessary for improving their matmuras: cheap labor, abundant land and suitably dry soils.

Research results from the project, based on farmer innovations, showed that digging wider shallower pits and lining them with thick layers of chaff can be very effective, if additional wide soil caps are applied to cover surface cracks. Possibly, plastic would do even better as a lining, but money to buy polythene is scarce and such plastic is often not available to farmers. Attempts have been made to use discarded sacks from the sugar industries.

Improved matmura systems have the potential to increase farmers' food security and better their economic position. Our initiatives showed that farmers in the Jebelmuoya villages could benefit from improved matmuras. Calculations indicate that improved matmuras could increase returns by up to 45%, even in the case of small-scale farmers; the larger the matmura, the higher the benefits.

A recent survey carried out in three villages in the area showed that farmers were aware of the advantages of developing the system. Forty percent of farmers questioned in the survey commended improved matmuras for their storage qualities and low cost. They particularly appreciated the reduced need for chemical protection and the security they provided against theft and fire

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

Currently, improved matmura systems are under-exploited, even though the knowledge accumulated through research, experience and farmer innovation shows that matmuras can be productively further developed and adapted. The absence of a policy environment capable of stimulating the use of research results beyond the target group of participating farmers and encouraging the exchange of information on this technology is partly responsible for this situation. It has lead to conditions in which farmers are unable to benefit from the information that exists and there is little encouragement to applying improvements.

It should be realized that in frequently occurring times of drought and crop failure, the farmers generally store what they get only for short periods, while the improvements made particularly apply to longer term storage, that is for periods including at least one rainy season.

At the strategic levels of economic planning and agricultural development, matmuras have also been largely ignored. They are not included in the storage capacity inventories drawn up by the Ministry of Economic Planning and Investment, and they are seldom mentioned in the lists of research and publications in agricultural bibliographies

M. Difficulties of the service or information as seen by the farmers concerned

The Jebelmuoya area in Sennar State is officially defined as rain-fed, un-demarcated land and has lower rainfall and poorer soils than the large mechanized farming schemes established in nearby demarcated areas. Smallholdings in Jebelmuoya vary considerably in size and are supervised by the Small Farmers' Union for Un-demarcated Areas. Unlike farmers 30 km away in the Sennar Agricultural Extension Unit, who also use the matmura system, smallholders in Jebelmuoya are not considered part of the modern sector and are, therefore, not eligible for government services.

Even chaff is often difficult to get when harvests are poor. Those farmers who are able to invest in improvements are after all not always able to benefit from the sale of well preserved sorghum, because in times when poverty and hunger are widespread, the local population is ready to accept whatever sorghum.

Their poverty has made the smallholder communities of Jebelmuoya particularly vulnerable to the climatic changes affecting the region as a whole. They stagger their sorghum planting in time to offset the risks of crop failure and need storage facilities that will preserve sorghum long enough to carry them through periods of crop failure and food shortage. However, at the moment there is little to encourage them to invest their meager resources in improving their matmuras. Information is scarce and practical help and advice largely unavailable.

There is an urgent need to disseminate these types of research result. The government extension services have an important role to play in this process but at the moment local farmers are largely excluded from extension networks. Even though there is an extension station in the nearby town of Sennar, officials there have no communication links with farmers in Jebelmuoya

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

The research project has shown that participation in addressing farmers' problems, by observation and targeted problem-solving at a micro-level, can increase the resilience of smallholders in areas of climate volatility. The capacity building task of improving farmers' access to information and extension is now in the hands of the Small Farmers' Union, which is currently lobbying for the area to be given demarcation status, so that it becomes eligible for planned agricultural development and extension

O. Chances of expanding the application of the improved example

It should be remembered that top-down interventions are likely to be less effective amongst the smallholder communities of Jebelmuoya than participatory approaches that focus on farmers' specific needs. One of the successes of the research initiative has been to show that only targeted participatory research can have far-reaching effects at local and regional level. However, the results of research and farmers *innovations must be disseminated, adapted and encouraged by appropriate policies and promoted by the agricultural extension services*

P. Related examples found elsewhere in the Province (or in the country for that matter)

For thousands of years farmers have used underground storage pits to preserve their grain in various African countries, among which Ethiopia, Kenya and Sudan. In Eastern and Central Sudan these pits are known as matmuras

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Yes, a list of research publications of the group at the University of Gezira in Wad Medani is available. There are also five more general publications, given here chronologically:

Bakheit NI, Stigter K, Abdalla AT (2001) Underground storage of sorghum as a banking alternative. LEISA Mag 17(1):13

Abdalla AT, Stigter CJ, Bakheit NI, Gough MC, Mohamed HA, Mohammed AE, Ahmed MA (2002) Traditional underground grain storage in clay soils in Sudan improved by recent innovations. Tropicultura 20:170–175

Stigter CJ, Abdalla AE (2004) Improved underground grain storage microclimate in cracking clay extends safe storage time by designing shallow pits, using chaff linings, constructing wide surface caps. Case study of economically beneficial agrometeorological applications & services and other success stories in agrometeorology for policy matters. In Baier W(Coord) CAgM Rep 93, WMO/TD 1202, Geneva, pp 32–35

Bakheit NI, Stigter CJ (2004) Improved matmuras: effective but underutilized. LEISA Mag 2(3):14

Bakheit NI, Ahmed MA, Stigter CJ, Mohamed HA, Mohammed AE, Abdalla AT (2005) Economic aspects of traditional underground pit storage (matmuras). The case of Jebel Muoya, Central Sudan. Sudan J Agric Res 5:89–96

R. Could research assist in improvement of the service/information and how?

For the time being, enough research has been done till locally new needs arise. Research into extension problems is urgently needed. Also research might be helpful in studying health problems due to micro-organisms and mycotoxin contamination of stored sorghum

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

Researchers in the Sudan have been studying the matmura systems for many years. In the 1960s, experiments were carried out in eastern Sudan where larger farmers are famous for constructing matmuras that can hold 200 t of grain. From time to time the government itself has made use of matmura technology. In 1985/1986 and

1986/1987, for example, the Agricultural Bank of Sudan used heavy machines to dig large non-cylindrical storage pits to preserve the country's bumper sorghum harvest

[Original submission edited by Kees Stigter, Ahmed el-Tayeb Abdalla and Naguib Ibrahim Bakheit; version for this book edited by Kees Stigter]

[Original submission obtained second prize in second INSAM contest of 2006]

II.14 <u>*Protocol number 14*</u>

Short name of example:

Improved design of millet based intercropping systems using on-station field research and microclimate manipulation

A. Country/Province where the example was found

Nigeria, Kano Province, Minjibir

B. Institute providing the example (with address)

Ahmadu Bello University, Soil Science Department, Institute of Agricultural Research, P.M.B. 1044, Samaru-Zaria, Nigeria

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Tunji Oluwasemire (kooluwasemire@yahoo.com), C.J. Stigter (cjstigter@usa.net), J.J. Owonubi (josephowonubi@yahoo.co.uk; DFRIN@skannet.com)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agrometeorology and Development (AD), Agrometeorological Services (AS), Crop Micrometeorology (CM), DRought (DR), Education and Training (ET), EXtension (EX), Multiple Cropping (MC), Operational Agrometeorology (OA), Policy Matters (PM), User's Needs in agrometeorology (UN)

E. Natural disaster(s) and/or environmental problems to which the example is related

Drought and erratic rainfall, Low and decreasing soil fertility as well as organic matter contents of sandy soils with low water holding capacity

F. Way, in which the example was found, defined and collected

The hypothesis was tested, for the most abundantly occurring intercrops in semi-arid northern Nigeria, that these systems are generally more efficient in resource use under drier conditions than sole crops. This was done for dry-land intercropping, with heterogeneous mixtures derived from patterns and varieties that farmers preferred, at low densities on-station. A quantitative project was set up on resource use, with soil water balances, dry matter production and yield determinations, leading also to numerical crop productivity/water use relationships

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Rainfed millet/cowpea, millet/sorghum/cowpea and a few comparable intercropping systems with groundnut

H. Regions of the county (or counties) where the example can be found

The Nigerian Sudan and Sahel savanna zones, which are also representative of the arid West African sub-region

I. Villages where the example can be found

Not applicable because the work was done on-station

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

The most dominant crop mixtures are millet/cowpea, millet/sorghum/cowpea, millet/cowpea/groundnut, sorghum/cowpea and sorghum/cowpea/groundnut. Cowpea has a dual purpose: the grain is used for human consumption and the remaining biomass as fodder for animals. Some cowpea varieties are planted specially within the intercrops for fodder production, producing little or no grain, to take care of animal feeds during the dry season The cowpea component of the mixtures also often consists of two types, i.e. fodder and grain types that differ in growth habit and maturation period. The cereals are grown for consumption and cash. Intercropping components adopted by farmers are grown at low densities, to minimise risks and exploit resources in a good cropping season well.

High year-to-year variability of rainfall, serious deep percolation and high wet soil evaporation losses are additional stresses. The efficient use of the limited effective rainfall in this zone is therefore a crucial factor for future increases in crop production, which should come primarily from increased yield per unit area of land. Low harvest index (HI) may result from the reduction in the supply of assimilates, when competition for water in the root zone occurs during the yield production stage.

Dry matter production and system productivity of the intercrops were higher or equal to the sole millet, when the relay planted cowpea productivity was higher in 2 dry years than in a wet year in between. When the rainfall was below normal, the intercropping systems showed better water use efficiency than all sole crops, with the exception of the case of millet with inorganic fertilizer side dressing, due to millet dominance exerted by earlier planting and heavy tillering. In a dry year, millet, particularly when intercropped, used limiting resources more efficiently for grain production. It showed better adaptation to moisture stress. In a previous wet year sole millet used water more efficiently than its intercrops with cowpea. The soil *fertility treatments did not create any statistically significant increases in yield and yield components of millet at harvest within the intercropping systems.*

All the crops sown sole and intercropped rooted beyond 1 m in the loose sandy soil. Sorghum root production was greater than for millet, while both cereals produced greater root densities than cowpea. Overlap of the roots of component crops suggests competition for resources. Cowpea produced greater root densities and achieved deeper rooting when intercropped with millet and/or sorghum than sole, suggesting adaptation and competitive ability under intercropping. Rooting depths of crops were shallower in a relatively wet season than when water was limiting. Root densities and proliferation of the cereals below the surface layer were much higher in low fertility soils than when nutrients were readily available. This is immediately useful knowledge as an agrometeorological service for designing such systems

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

The soils of the Northern Savanna zone are known to be inherently low in organic matter, N and P while K and micronutrient deficiencies are becoming important in arable lands that are being subjected to intensive and continuous cropping. The government and its agencies are promoting the use of high inputs as chemical fertilizers and insecticides, but the structural adjustment programmes diminished subventions. The seasonal increases in the prices of these inputs, that rose earlier because of the decreasing value of the local currency, have caused a decline in the use of such inputs.

Moreover, the generally unfavourable economic factors related to prices for agricultural produce are not encouraging the use of increased inputs either, while land use intensification continues. There is, therefore, more need for better understanding of the traditional intercropping systems that we have been working on. This would improve the possibility of mitigating the limiting factors, as well as making optimum use of the limited resources

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

Crop water use of millet-based cropping systems was increased by high annual rainfall. Improved soil fertility status compared to OM (organic matter only) caused no or only marginal increases in 1994 and 1995 in the low density intercrops, and only an appreciable response (of 20%) in sole millet in 1995. The generally lower planting densities in intercropping (≈ 50%) than recommended in sole cropping, suggest that the varieties in use may not be the most appropriate, while their optimum planting densities with intercrops have not been achieved at the farmers' level to optimise soil water conservation and use.

To fight land degradation, a consistent incorporation of organic manure at seasonal level is a way of improving soil physical and chemical conditions aimed at conserving soil water. The generation and increased use of farmyard manure during this period of annual removal of government subsidy on inorganic fertilizer would enhance soil water conservation in these farming systems. The improvement of the soil nutrient status by an increased application of organic manure may also encourage the manipulation of the intercrop components, such that an increase in plant densities would make better use of soil water that would otherwise have been lost to soil evaporation and deep percolation beyond the rooting zones

M. Difficulties of the service or information as seen by the farmers concerned

The farmers' practice of planting millet and/or sorghum earlier in the intercropping systems relative to the cowpea components affords the cereal components, especially millet, with a relatively faster rate of assimilate accumulation, more competitiveness for resources than the other crops in association. The implication of this practice is the negative effects on cowpea yields as shown in our case

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Other design consequences for further agrometeorological services are that an improvement of these cereal/legume intercropping systems in terms of microclimate improvement may involve a reduction in plant densities of the tillering and faster dry matter accumulating millet component, while the low growing and ground covering cowpea component density is increased. This may result in more efficient use of soil water while the intercropping systems radiation interception, soil water conservation, ground shading for weed suppression and reduced soil temperature fluctuations and soil evaporation are enhanced. The introduction of shorter duration sorghum must combine superior yield with farmers' desirable traits that would meet their socio-economic needs

O. Chances of expanding the application of the improved example

The density and morphological characteristics of crops in association influence the microclimate within the various cropping systems. The reduction of soil radiative and heat exchanges (reduced surface soil temperature fluctuation), by a well developed low growing cowpea component in an intercropping system, is capable of reducing soil evaporation better than in the sole cereal systems and hence offers a better soil water conservation practice in the arid and semi-arid zone of Nigeria.

An answer with a view of improving the cereal/legume systems in the Nigerian arid and semi-arid zones should therefore include genetically superior crop cultivars and the manipulation of the component densities along with the improvement of microclimatic variables.

The results learn that abundant organic manure in combination with agrometeorological services on intercrop manipulation related microclimate improvements may control near surface land degradation in northern Nigeria under acceptable sustainable yields. Appropriate policy environments, in economics and research, must enhance this

P. Related examples found elsewhere in the Province (or in the country for that matter)

We have no knowledge of comparable research

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

For the above summaries we made use of the following papers:

Oluwasemire KO, Stigter CJ, Owonubi JJ, Jagtap SS (2002) Seasonal water use and water yield of millet based cropping systems in the Nigerian Sudan Savanna near Kano. Agric Water Manag 56:207–227

Stigter KCJ, Kinama J, Zhang Yingcui, Oluwasemire TKO, Zheng Dawei, Al-Amin NKN, Abdalla AT (2005) Agrometeorological services and information for decision-making: some examples from Africa and China. J Agric Meteorol (Jpn) 60:327–330

Stigter CJ, Oteng'i SBB, Oluwasemire KO, Al-Amin NKN, Kinama JM, Onyewotu LOZ (2005) Recent answers to farmland degradation illustrated by case studies from African farming systems. Ann Arid Zone 44:255–276

Stigter K, Oluwasemire T, Onyewotu L, Rashidi AGM, Oteng'i S, Murthy VRK, Nguyen Van Viet, Koesmaryono Y, Bakheit NI (2005) Agrometeorological services making a difference for poor farmers. I. Why it does not happen. Closure paper used in the Roving Seminar "Agrometeorological services: theory and practice" given in Teheran (2005), Hyderabad (2006), Bloemfontein (2008) and Yogyakarta (2009). Available as PowerPoint presentation and in the documentation bundle of the Roving Seminar, 8pp

Stigter K, Oluwasemire T, Onyewotu L, Oteng'i S, Kinama J, Zheng Dawei, Zhao Caizia, Zhang Yingcui, Murthy VRK, Rashidi AGM, Abdalla AT, Al-Amin NKN, Bakheit NI (2005) Agrometeorological services making a difference for poor farmers. II. How it can be done. Closure paper used in the Roving Seminar "Agrometeorological services: theory and practice" given in Teheran (2005), Hyderabad (2006), Bloemfontein (2008) and Yogyakarta (2009). Available as PowerPoint presentation and in the documentation bundle of the Roving Seminar, 10pp

R. Could research assist in improvement of the service/information and how?

As indicated above under N. and O.

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

None

[Original submission edited by Kees Stigter and Tunji Oluwasemire; version for this book edited by Kees Stigter]

[Original submission obtained third prize in second INSAM contest of 2006]

II.15 <u>*Protocol number 15*</u>

Short name of example:

Design of wind protection agroforestry from experience in a demonstration plot of hedged agroforestry

A. Country/Province where the example was found

Kenya, Rift Valley Province

B. Institute providing the example (with address)

Originally the University of Nairobi, Department of Meteorology. Now: Western University of Science and Technology, Department of Research, Development and Documentation, P.O. Box 190-50100 Kakamega, Kenya

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Silvery B.B. Oteng'i (sbotengi@wust.ac.ke or sbotengi@yahoo.com), C.J. Stigter (cjstigter@usa.net), J.K. Ng'ang'a (John.Nganga@meteo.go.ke), H.-P. Liniger (liniger@giub.unibe.ch)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agro-Forestry (AF), Crop Micrometeorology (CM), EXtension (EX), Multiple Cropping (MC), Climate Variability (CV), Education and Training (ET), Operational Agrometeorology (AO), RIsk in weather and climate (RI), User's Needs in agrometeorology (UN), DRought (DR)

E. Natural disaster(s) and/or environmental problems to which the example is related

Mechanically damaging and desiccating winds, Drought and erratic rainfall, Water runoff from plots; Low and decreasing soil fertility as well as low organic matter contents

F. Way, in which the example was found, defined and collected

In consultation with the Swiss Laikipia Research Project in Nanyuki and local provincial authorities, demonstration plots were decided on in which a traditional maize/bean intercrop was grown in a wind protective agroforestry system with all around hedges and trees in this semi-arid region. A quantitative project was set up to determine the feasibility of this set up for the farmers that recently immigrated to *this area from the Central Province of Kenya, as to yields and their sustainability compared to non-agroforestry control plots*

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Small scale Low External Input Agriculture intercropping of maize and beans that immigrated farmers used to grow in the areas they came from

H. Regions of the county (or counties) where the example can be found

Laikipia District of Rift Valley Province. Rain shadow of Mount Kenya.

I. Villages where the example can be found

Matanya

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

The Laikipia verto-luvisols, originally open grassland with scattered Acacia trees, are now denuded of vegetation or litter (mulch), with organic matter contents of 3–4%. Like elsewhere in semi-arid areas, the soils suffer from heavy weather impacts such as high radiation loads, that cause high soil temperatures, excessive rain showers and sometimes strong winds that dry soils. The combination of N stress with water stress is additive on both carbon exchange and water relation impacts on plant growth. Cultivation enhances mineralization from fresh organic matter.

The benefits of trees (shading, mulching, wind protection etc.) to degraded soils of semi-arid areas often remain low because of low biomass production in seasons with inadequate rainfall. However, in seasons with adequate rainfall there is improved soil water holding capacity, water infiltration and adequate organic matter. Hedges, assisted by the trees, solved existing wind problems with the blowing off of maize stalk mulches and mechanical shaking of maize. **Grevillea robusta** *(Silky Oak), used in our agroforestry plots with maize and beans, belongs to the non-leguminous multipurpose trees, which do not fix nitrogen but deplete nutrient resources, replacing only some through leaf fall. It was found that* **Coleus barbata** *live-fence and* **Grevillea** *vigorously competed with an intercrop for soil moisture, thus lowering the heights and yields of the maize (***Zea mays*** HB511) plants next to the hedges. In the demonstration plots the hedge roots were therefore pruned and half of the grevillea trees as well.*

The moisture benefits to the intercrops of maize and beans were stronger closer to the pruned trees, while unpruned trees typically used more moisture and therefore exhibited stronger competition, thereby negatively influencing yields. As a *consequence of this spatial moisture behaviour, these and other effects or their absence appeared indeed similar for the driest and the wettest of the rainy seasons, so the same is likely to apply to yields in general. The agroforestry intervention with pruned older trees and maize stalk mulching did not negatively influence maize yields in the wettest season and showed a positive effect on maize biomass yields in the driest season. Compared to the controls, the latter season kept the bean seed yields the same, but in the wetter season bean seed yields were negatively influenced by the intervention, due to competition.*

Comparison of yield differences in mulched and pruned plots in the wettest season indicated that for maize pruning was more operational than mulching under these conditions, while for the low bean component yields both were effective. A combination of the water conservation measures root-pruning, mulching and minimum tillage was to be preferred for the maize/beans intercrop in this system for a very low rainfall season. More overlapping of depletion zones of the three root systems would have influenced the pruned plot yields of the intercrop more seriously

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

In Kenya, people are forced to leave higher and medium potential areas, often in highlands. Further land division into smaller plots would make farming a no longer economically viable undertaking. The resulting migration necessarily takes place to more marginal lands. Unadapted intercropping systems, introduced by immigrants, are causing low yields and land degradation. Water runoff, increasing climate variability and dietary habits of the population are also involved.

In Laikipia district deforestation, overgrazing and strong winds worsen the situation. An ideal protective mixed cropping system for these farmers would be an agroforestry system in which tree roots and crop roots colonize different soil layers and system components render services mutually. Because of initially high risks, on-station demonstration plots were chosen for introduction of such systems.

Farmers could be shown that combining the root pruned hedge protected system with root pruned **Grevillea robusta** *trees made it economically more attractive and made it aerodynamically more efficient to diminish mechanical damage to the intercrops and improve soil water availability to these crops*

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

It is another example of a typically local problem, experienced in this case by farmers that were forced to emigrate from higher potential areas in Kenya, because of population pressure and carrying capacity problems of the land available in their areas of origin. Demonstration farms had to be set up to introduce mulched agroforestry, to make it possible for them to keep growing their maize/bean intercrops to which they were used.

During part of the growing season strong winds are experienced. It was found that gaps in the hedges could be devastating if in the direction of prevailing winds. Gaps between the top of the hedges and the lowest biomass of the trees diminished the protection efficiency of the agroforestry system. Turbulence generated by buildings and large trees near to the demonstration plots negatively influenced crop growth locally, indicating the sensitivity of the crops for mechanical wind damage by the winds concerned

M. Difficulties of the service or information as seen by the farmers concerned

Some participatory experiments were done on-farm under an existing dense tree system. In seasons with higher on-farm yields, the maize plants grew shorter due to shade influence on the dry matter distribution within the crop and due to the sensitivity to water stress of both net photosynthesis and partitioning of assimilates. A few grains and cobs were obtained in addition to the stover biomass.

The control plots had much higher maize biomass than the agroforestry plots, confirming the influence of heavy shade by too closely planted trees. Pruning effects were clearly observed, but mulching appeared to have negative effects, since it added to shading, and no effects in the controls

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

The results learn that under the very difficult semi-arid conditions in Laikipia, the mulched tree cum hedge pruned agroforestry system overall helped to limit land degradation. However, the farming conditions are extremely marginal and economically more viable systems must be developed as (agrometeorological) services, to help the migrated farmers concerned.

It may again be concluded that some configurations of trees, with the right distributions of biomass, can modify airflow positively and in this case sufficiently reduce mechanical damages of the protected crops and prevent the blowing off of mulches. However, strong biomass gradients, such as in gaps, as well as generation of additional turbulence should always be prevented, like this is also the case in the design of shelterbelts

O. Chances of expanding the application of the improved example

Depending on local initiatives and further research assistance

P. Related examples found elsewhere in the Province (or in the country for that matter)

Not applicable because of unique demonstration plots

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Details of the above information can be found in the following chronological papers:

Oteng'i SBB, Stigter CJ, Ng'ang'a JK, Mungai DN (2000) Wind protection in a hedged agroforestry system in semi-arid Kenya. Agrofor Syst 50:137–156

Stigter CJ, Mohammed AE, Al-Amin NKN, Onyewotu LOZ, Oteng'i SBB, Kainkwa RMR (2002) Agroforestry solutions to some African wind problems. J Wind Eng Ind Aerodyn 90:1101–1114

Stigter CJ, Al-Amin NKN, Otengi SBB, Kainkwa RMR, Onyewotu LOZ (2003) Scattered trees and wind protection under African conditions. In: Ruck B, Kottmeier C, Mattheck C, Quine C, Wilhelm G (eds) Wind effects on trees. University of Karlsruhe, Karlsruhe, pp 73–80

Oteng'i SBB, Stigter CJ, Ng'ang'a JK (2005) Understanding maize/beans intercropping yield distributions from water conservation measures in a hedged agroforestry system in semi-arid Laikipia District, Kenya. J Sci Technol Educ Manag (JSTEM) 1(1):6–33

Stigter CJ, Oteng'i, SBB, Oluwasemire KO, Al-Amin NKN, Kinama JM, Onyewotu LOZ (2005) Recent answers to farmland degradation illustrated by case studies from African farming systems. Ann Arid Zone 44:255–276

Stigter K(CJ), Oteng'i S, Al-Amin NKN, Onyewotu L, Kainkwa R (2005) Wind protection designs from measurements with simple wind equipment in four African countries in research education capacity building projects. Paper 4.1 in WMO Instruments and Observing Methods Report 82, WMO/TD 1265, Geneva, 7 pp [Also available on CD-ROM]

Oteng'i SBB, Stigter CJ, Ng'ang'a JK, Liniger H-P (2007) Soil moisture and maize/beans yields under different management in a six years old hedged agroforestry system in semi-arid Kenya, for two successive contrasting seasons. Afr J Agric Res 2(3):89–104

R. Could research assist in improvement of the service/information and how?

See under N

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

It is our experience that the scientific level of agroforestry and agricultural journals and publications is suffering a lot from agronomical scientific traditions that do not belong in this kind of research under inhomogeneous conditions. A physical approach has been shown several times in our research endeavours to be a much easier way of handling replicated data and with comparable or better results. The feeling for this approach is often absent among agro-foresters. Our many publications about agroforestry subjects in journals like "Theoretical and Applied Climatology", "International Agrophysics", "Agricultural and Forest Meteorology", "Journal of Wind Engineering and Industrial Aerodynamics", "Agroforestry Systems" and "Arid Land Research and Management" do illustrate these points

[Original submission edited by Kees Stigter and Silvery Oteng'i; version for this book edited by Kees Stigter]

[Original submission obtained first honorary mention in the second INSAM contest of 2006]

II.16 <u>*Protocol number 16*</u>

Short name of the example:

Applying straw mulch on winter wheat in winter to improve soil moisture conditions

A. Country/Province where the example was found

China, Hebei Province

B. Institute providing the example (with address)

Meteorological Institute of Hebei Province (Provincial Meteorological Administration), No.178, Tiyu Nandajie, Shijiazhuang, 050021 China P.R.

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Chunqiang LI (chunql@sohu.com; chunqiangl@gmail.com)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

DRought (DR), Agrometeorological Services (AS), Crop Protection (CP), EXtension (EX)

E. Natural disaster(s) and/or environmental problems to which the example is related

Agricultural drought, Water resources shortage

F. Way, in which the example was found, defined and collected

From the extension program and operational services by the Agrometeorological Center of Hebei Province, in collaboration with the Chinese Academy of Meteorological Sciences (CAMS), that is part of the Chinese Meteorological Administration (CMA), and local weather stations, also including some research results from the Meteorological Institute (Provincial Meteorological Administration) of Hebei Province and CAMS

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Irrigated or rainfed winter wheat cropping or corn-winter wheat cropping (corn-winter wheat-corn sequential system, no intercropping). For the latter:

June–September for sole corn, after the wheat has been harvested; October–June for sole wheat

H. Regions of the county (or counties) where the example can be found

Winter wheat planting areas in the North-China Plain

I. Villages where the example can be found

Research work has been done at the China – Canada Agricultural Experiment Station, Dengzhuang, Hengshui, Hebei Province. And the extension areas were also in Shenzhou and Fucheng counties of Hengshui, and in Yongnian county of Handan in Hebei Province

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

By comparison with uncovered winter wheat, it was shown that the soil water content of winter wheat mulched with corn straw was much better, especially before the wheat elongating stage in spring. It could enhance soil water by 1.3%, equivalent to 10 mm rainfall.

The microclimate of wheat fields was changed evidently under straw mulching. According to field measurements, air temperature and turbulence near the surface increased, and air humidity and soil temperature decreased in mulched wheat fields. Looking at the energy balance, mulching caused an increase of sensible heat flux and a decrease of latent heat flux, so the soil evaporation from mulched wheat fields was reduced and the transpiration of wheat was increased after the elongation stage.

Attention: The total evapotranspiration may not have increased; it only changed the water consumption in time and way. In winter (mulched period), soil evaporation decreased and soil water increased; after the elongation stage, wheat transpiration increased. The water for soil evaporation was converted to wheat transpiration through mulching wheat in winter times

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

Through 2 years of extension service, it brings a better result, that includes saving water resources, reducing production costs, and enhancing crop yields

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

From our experience of the extension for this technology, there is little difficulty for farmers to understand and accept it, but it should give them a good example

M. Difficulties of the service or information as seen by the farmers concerned

No such difficulties were expected as long as the extension service gets convinced

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Water is a problem for agricultural production in Hebei Province. Winter wheat is planted in the dry season of the year, so it is very obvious that water relations are the foremost problem encountered. Integrated drought mitigation measures are needed, and weather forecast information is also expected by farmers

O. Chances of expanding the application of the improved example

Depending on where water resources shortages occur

P. Related examples found elsewhere in the Province (or in the country for that matter)

Henan Province, China

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Yes, research results on this work and the example were dealt with in various journal papers and book chapters that were published on it. They are all in Chinese

R. Could research assist in improvement of the service/information and how?

Straw mulching was mainly in the winter season, it has multiple functions such as maintaining soil temperature, increasing soil moisture and soil fertility, but the adequate length of straw mulching needs to be studied further for improving field operations

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

We know that the extension services demonstrated the results, but drought is a complex problem affecting agriculture. The duration and severity of drought, especially the information as early warning and prediction of drought needs to be provided timely and in a suitable way to farmers

[Original submission edited by Li Chunqiang and Kees Stigter; version for this book edited by Kees Stigter]

[Original submission obtained second honorary mention in the second INSAM contest of 2006]

II.17 *Protocol number 17*

Short name of example:

Using shade trees to ameliorate the microclimate, yields and quality of tea

A. Country/province where example was found

India, Himachal Pradesh, Palampur

B. Institute providing the example (with address)

Dr. Rajendra Prasad and Dr. K.L. Sharma, Agrometeorologists, Department of Agronomy, Agrometeorology section CSK Himachal Pradesh Agricultural University, Palampur 176 062, Himachal Pradesh, India. Work done with Tea Husbandry and Technology Research Station, CSK Himachal Pradesh Agricultural University

C. Researchers that collected/described this example (with the e-mail addresses)

Dr. Rajendra Prasad (agron@hillagric.ernet.in; rprasad57@gmail.com), Dr. K.L. Sharma (KlSharmahpau@rediffmail.com)

D. Field(s) of Agrometeorology to which the example belongs:

[Use the fields of interest defined for registration of members of INSAM]

Crop Protection (CP), Climate Under cover (CU), Agro Ecosystems (AE)

E. Natural disasters (s) and/or environmental problems to which the example is related

Advection of hot air; high rainfall and hail storms during the summer; soil erosion; low water holding capacity and low fertility of silty clay loam soils; and high solar radiation loads. Shading by these trees provides a number of benefits to tea plantations including microclimatic improvement and resultantly higher growth rates and better quality of tea leaves as well as better economic returns

F. Way, in which the example was found, defined and collected

This growing of shade trees is an age old technique, practised in the tea gardens in Himachal Pradesh for known benefits. It attracted the attention of the authors while they were working in the tea gardens

G. Farming system(s) in which the agrometeorological service is applied or to whom the agrometeorological service is provided for actual use

Tea gardens under shade trees

H. Region of the country (countries), where the example can be found

Slopes of Assam, Darjeeling, Uttranchal and South India

I. Villages where the examples can be found

Example is followed in almost all the major Tea Estates of the region

J. Describe the good example of the operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problems(s) concerned

It is an established fact that umbrella type shade trees covering the tea gardens indeed protect them from direct sunlight, scorching heat and warm air currents. High temperatures in unshaded tea in the peak growing season drastically reduces tea yields because tea leaf temperatures exceed critical values and photosynthesis slows down.

The compatible shade tree species filter solar radiation by cutting off near infrared sun flux and transmit sufficient light intensity for optimum photosynthesis. This results in lower ambient, leaf and soil temperatures and the retaining of soil moisture. It increases leaf area, number of pluckable shoots, so yields. It improves tea quality to some extent by promoting the content of caffeine, polyphenols and other taste determinants.

The radiation is reduced by 35–40% of total incoming solar radiation. The shading trees generally belong to leguminosae families, having the capacity of fixing atmospheric nitrogen and generating a good amount of foliage, shedding of the same at the time when the organic matter is greatly needed for building up the fertility levels and providing the requisite sunlight at the critical stage to the tea plantation. The by-products of shade trees provide fuel wood and hence save energy in the tea processing industry.

It is an agrometeorological service worth putting into practice and suitable for pushing it for recommendation for tea planters. The growing of shade trees should be encouraged for its multifarious and benevolent effects on tea yields and quality tea production

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increases in income due to the services or information

The beneficial effects are doubtlessly known, among the six shade species viz. **Albizzia**, **Pinus**, **Aleurites**, **Calophyllum**, **Celtis** *and* **Prunus** *compared to Tea alone. Studies found* **Albizzia** > **Aleurites** > **Calophyllum** > **Celtis** > *Tea alone* > **Prunus** *and* **Pinus** *were promising in order of this preference.* **Albizzia** *and* **Aleurites** *increased the weight of tea produced per hectare by 56 and 41% respectively over the shadeless control. The theaflavin and thearubigins contents, the colour and brightness of the produced tea were highest under* **Albizzia**. *The available light was 65, 63 and 61% respectively under* **Albizzia**, **Aleurites** *and Calophyllum.*

The current example highlights that **Albizzia chinensis** *followed by* **Aleurites fordii** *and* **Calophyllum elatum** *are the most propitious associates of tea. For establishing new tea gardens, the above three tree species should be preferred as the shade tree in the area or under similar agro-ecological conditions.*

The economical benefits are still required to be assessed and documented

L. Difficulties encountered in introduction and use of good example of agrometeorological services or information

Tea planters are largely convinced by this practice and shade trees naturally regenerate in the tea gardens. Hence there appears no difficulty in introduction of this practice in the tea gardens in Himachal Pradesh

M. Difficulties of the service or information as seen by the farmers concerned

No material available

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Generally, in the order of a 100 trees are maintained over 1 ha area. A higher density of shade tree species takes away too much of the direct sunlight, which promotes the attack of Blister Blight, which is a major tea fungal disease.

With maintaining an optimum density of shade trees, also competition for water and nutrients is kept within limits. A well planned experiment could test the optimum planting densities of shade tree species and quantify the benevolent effects of this practice

O. Chances of expanding the application of the improved example

Looking into the overall beneficial effects of shade trees along with its additional benefits drawn from this planting, they should be vigorously supported as they can easily establish in high rainfall areas under natural regeneration conditions

P. Related examples found elsewhere in the Province (or in the country for that matter)

Windbreaks and shelterbelts provide improved microclimatic conditions in food and fruit crops in the region

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Yes, PhD research with a quantitative analysis of shade tree-tea system interactions was carried out to study the effect of different shade tree species on growth, yield and quality of tea

R. Could research assist in improvement of the service/information and how?

Studying incident radiation over bare ground, under the shade of different tree species and over the top of tea bushes under these different species, can help standardize techniques for working out optimum densities of different species of shade trees

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

The local adaptive strategies in tea production to combat weather calamities like excessively high temperature, hail, drought etc. must find its basis deep into the traditional knowledge and indigenous technologies which have stood the test of time. It should be seen as an important agrometeorological service, that should support the action of tea planters for higher yields and quality in tea

[Original submission edited by Rajendra Prasad; version for this book edited by Kees Stigter]

[Original submission obtained third honorary mention in the second INSAM contest of 2006]

II.18 *Protocol number 18*

Short name of example:

Explaining wind protection of coffee from umbrella shade trees

A. Country/Province where the example was found

Tanzania, Kilimanjaro Region

B. Institute providing the example (with address)

University of Dar es Salaam, Department of Physics, Agricultural Physics section (work done with the Lyamungu Coffee Research Institute, Moshi), P.O. Box 3065, Dar es Salaam, Tanzania

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Reuben M.R. Kainkwa (kainkwa@udsm.ac.tz), C.J. Stigter (cjstigter@usa.net)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agro-Forestry (AF), Agrometeorological Services (AS), Crop Protection (CP), EXtension (EX), RIsks in weather and climate (RI)

E. Natural disaster(s) and/or environmental problems to which the example is related

Mechanical wind damage of coffee trees that could be diminished by the presence of shade trees

F. Way, in which the example was found, defined and collected

The late Director of the Lyamungu Coffee Research Institute was visited by a Ph.D.-student and his co-supervisor and he mentioned this problem as a possible research subject. He indicated that the extension services wanted to cut the shade trees as no longer recommended. However, the farmers refused because of their experience with the wind protection provided by these trees to the coffee, particularly during high winds preceding showers on these slopes of the Kilimanjaro

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Coffee under shade trees

H. Regions of the county (or counties) where the example can be found

Slopes of mount Kilimanjaro, northern Tanzania and southern Kenya

I. Villages where the example can be found

Unknown. Work done at Lyamungu Coffee Research Institute (Location 03° 14′ S, 37° 15′ E, 1,250 m altitude)

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

It was proven that, in comparison with unprotected coffee trees, the umbrella type shade trees indeed protected the coffee from mechanical damage of vertical air movements preceding showers. Tunneling effects from the trees were quantified and appeared relatively small and not damaging.

It was an agrometeorological service to recommend through the Coffee Research Institute to the extension service and farmers that the shade trees should be kept for wind protection

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

These features are unknown

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

Introduction was not in our hands. There were no direct contacts with extension service or coffee farmers

M. Difficulties of the service or information as seen by the farmers concerned

No such difficulties were expected as long as the extension service got convinced

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Not known to us

O. Chances of expanding the application of the improved example

Depending on where these wind damage problems occur. Possibly very locally related to the slopes of the Kilimanjaro mountain

P. Related examples found elsewhere in the Province (or in the country for that matter)

Unknown

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

The example was dealt with in various journal papers and book chapters on solving wind problems of small holders in Africa. Details of the above information can be found in the following papers:

Kainkwa RMR, Stigter CJ (2000) Measuring wind gradients in agroforestry systems by shaded Piche evaporimeters I. Validation of the square-root dependence on wind speed. Intern Agrophys 14:279–289

Stigter CJ, Kainkwa RMR, Oteng'i SBB, Onyewotu LOZ, Mohammed AE, Ibrahim AA, Rashidi MGM (2000) Measuring wind gradients in agroforestry systems by shaded Piche evaporimeters II. Accuracies obtained in some African case studies. Intern Agrophys 14:457–468

Stigter CJ, Mohammed AE, Al-Amin NKN, Onyewotu LOZ, Oteng'i SBB, Kainkwa RMR (2002) Agroforestry solutions to some African wind problems. J Wind Eng Ind Aerodyn 90:1101–1114

Stigter CJ, Al-Amin NKN, Otengi SBB, Kainkwa RMR, Onyewotu LOZ (2003) Scattered trees and wind protection under African conditions. In: Ruck B, Kottmeier C, Mattheck C, Quine C, Wilhelm G (eds) Wind effects on trees. University of Karlsruhe, Karlsruhe, pp 73–80

Stigter KCJ, Oteng'i S, Al-Amin NKN, Onyewotu L, Kainkwa R (2005) Wind protection designs from measurements with simple wind equipment in four African countries in research education capacity building projects. Paper 4.1 in WMO Instruments and Observing Methods Report 82, WMO/TD 1265, Geneva, 7 pp [Also available on CD-ROM]

R. Could research assist in improvement of the service/information and how?

Studying vertical air movements below and above the shade trees and above unprotected coffee would give more details on the actually damaging air movements.

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

We know that the extension services got the results, but it was not followed up what happened to the shade trees above coffee in the area in the years after these results had been obtained

[Original submission (2006) edited by Kees Stigter; version for this book edited by Kees Stigter]

II.19 Protocol number 19

Short name of example:

Development and establishment of a drought early warning system

A. Country/Province where the example was found

Cuba

B. Institute providing the example (with address)

Camagüey Meteorological Centre, Carretera de Nuevitas, Km 7 $^{1}/_{2}$, Camagüey, Cuba

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Roger E. Rivero Vega (roger@met.cmw.inf.cu)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

DRought (DR), Early Warning and monitoring (EW), Natural Disasters (ND), Agrometeorological Services (AS)

E. Natural disaster(s) and/or environmental problems to which the example is related

Meteorological and agricultural drought

F. Way, in which the example was found, defined and collected

All the work described was done, from the very beginning, by the author and his collaborators

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Specially designed to be useful to governmental and NGOs planners and decision makers at the local, municipal and provincial levels. But it is also used in direct services to farmers, farmers associations and governmental insurance companies

H. Regions of the county (or counties) where the example can be found

Provinces of Camagüey and Las Tunas. There is also a National version, which has been occasionally used to give warnings to other regions of the country

I. Villages where the example can be found

This item doesn't apply to example given

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

Using all available daily reporting meteorological stations from the Institute of Meteorology (INSMET) and all rain measuring stations of the National Institute for Water Resources (INRH), SAT calculates radiation, water and energy balances to estimate atmospheric drought index (P/E0) and ecosystem drought index (E/E0). The first index is used as a predictor for the second one, that is physically (not statistically) identified as an indicator of agricultural drought. Historically the system has had three different versions identified as SAT I, SAT II and SAT III. The making of SAT IV is underway. The versions differ among them in spatial resolution (point, region) and temporal resolution (10 days period and daily) but also in output form and in water balance method. SAT III is mounted on a Geographical Information System created by the same authors. Surprisingly enough all three versions satisfy different needs and are actually run in parallel.

SAT I gives as output all estimated terms of radiation, water and energy balances, and classified indexes, for 15 specified regions (grossly consisting in municipal terms except for two large ones, which are subdivided in central and coastal areas) in decadal time steps. SAT II does the same at 75 points with daily time steps. SAT III has an output in gridded form and maps with variable horizontal resolution (about 5 min) and makes weekly summaries. Final assessment is man made (not automated).

Service is given in many different ways:

1. *When asked by governmental authorities*
2. *When convened with different end users (agricultural and insurance sectors)*
3. *When internally convened with other weather/climate/agrometeorological service.*
4. *When requested by non-regular users*
5. *When Agrometeorological Services forecast or detect agricultural drought at any point/region of the monitored area.*

First version was built simultaneously with our National Meteorological Drought Surveillance System (1993) as soon as we arrived at the conclusion that this last system, based only on statistical analysis of precipitation amounts, couldn't characterize whether agricultural systems were under water stress conditions or not. As an interesting fact it should be said that this effort on the monitoring and forecasting of drought was requested by our national authorities on the basis of the famous 1986–1987 drought and made in parallel with national assessments of the impact of climate change on the agricultural and forest sectors.

SAT I went into internal operational service in November 1994 and started as a public service in September 1995 (this phase was needed because iterative internal procedures and algorithms converged at that date). This is related to the problem that, when such a system starts monitoring, the initial soil water content is never known. September 1995 was the exact moment for the system to predict the 1995/1996-winter drought that affected our area and that made the government to declare "drought emergency in Camagüey". This winter drought went into history as the "Camagüey cattle emergency" and established once and for all the relevance of our agricultural drought early warning system

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

This item doesn't directly apply to our example, but some information of this kind is given in item S.

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

Low development of communication networks linking providers of the service directly with producers at the farm levels. This problem doesn't exist with agricultural and governmental decision makers at municipal and provincial levels, because all means are employed: e-mail, telephone, telex and regular personal meetings

M. Difficulties of the service or information as seen by the farmers concerned

Again low development of communication networks at the farm levels. Although decision makers at levels higher than farms are totally satisfied with the service received, providers are not satisfied because we think that it is perfectly possible to give still much more information needed for the decision making process at all levels of society

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Services are being extended to include not only meteorological and agricultural drought but an early warning system for hydrological drought (ongoing research project). A new Web-based SATIV version is being made (ongoing research project) and a national version (ongoing research project) including pest and diseases forecasts is also being made. These three projects were approved and funded simultaneously in 2004–2005. They are all in execution. First version of the hydrological drought system will be in operational trial phase at the end of this year (2005).

O. Chances of expanding the application of the improved example

Chances are infinite, but authors sincerely believe that the effort should be made on-site, meaning that we don't think we have made "a universal software/system". Systems such as this should be tailored according to local technological, geographical and institutional conditions (including political organization)

P. Related examples found elsewhere in the Province (or in the country for that matter)

Not enough information available to us

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Yes. There are research results previous to the operational use of the system in 1994 and there are research results made with the use of one or another of the three different versions of it. The system itself received a Provincial Science Award in 1996 and (as part of wider studies) received a National Science Award in 1988 and another in 2002

R. Could research assist in improvement of the service/information and how?

Yes, definitely. In fact there are three ongoing research projects (2005–2008) to this end. The system could also be improved using radar measured precipitation amounts, satellite measurements and improved water balance models. But it is clear for all of us that the use of remote sensing would be very costly for operational systems that work at daily time steps. In this sense you could say that we are limited by funds

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

Our governmental institutions rely very heavily on the existence of this service. To work without it would be unconceivable to them now, after 10 years of depending on its existence. It is taken for granted that this service has been fundamental in all adapting measures and actions that have been taken to relieve the negative impact of drought in Camagüey, including saving nearly one hundred thousand of cow heads and the maintenance of milk production levels.

But a complete economic assessment has not been made owing (in our opinion) to two basic reasons:

1. *Social and political impact are so obvious that nobody question the role of the system*

2. *The operation of the system is practically inexpensive and needs only a disciplined operational meteorological network and a bunch of dedicated people*.

Dra. Rosa Elena Simeón (former Minister of Science, Technology and Environment), Eng. Alfredo Jordán Morales (Minister of Agriculture), Gen. Guillermo Rodríguez del Pozo (former General in Chief of the National Civil Defence) and Provincial Governments Council (3–4 different representatives in 10 years) have described the situation in the same terms, at different and independent occasions:

> *The most important achievement of the Early Warning System for Agricultural Drought in Camagüey, has been the creation of a new culture on drought problems and how to deal with them. This culture doesn't exist anywhere else in Cuba and should be extended as far as possible*

[Original submission (2005) edited by Roger E. Rivero Vega; version for this book edited by Kees Stigter]

[Original submission won first prize in the first INSAM contest (2005)]

II.20 <u>*Protocol number 20*</u>

Short name of example:

Development of a web-based optimal irrigation calendar

A. Country/Province where the example was found

Portugal

B. Institute providing the example (with address)

Centro Operativo e de Technologia de Regadio, Quinta de Saude – Apartado 354, 7801-904 Beja, Alentejo

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Jorge Maia (jorge.maia@cotr.pt), Miguel Castro Neto (Mneto@agriciencia.com), Isaurindo Oliveira (isaurindo.oliveira@cotr.pt)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agrometeorological Services (AS), EXtension (EX), Operational Agrometeorology (OA)

E. Natural disaster(s) and/or environmental problems to which the example is related

Efficient water use in agriculture, The need to know agricultural water demands

F. Way, in which the example was found, defined and collected

Based in international methodologies (FAO) and some applications around the world

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

Irrigated areas

H. Regions of the county (or counties) where the example can be found

Alentejo and Algarve regions

I. Villages where the example can be found

Elvas, Redondo, Beja, Odemira, Evora, Ferreira do Alentejo, Aljustrel, Serpa, Moura and Alvedade do Sado (Alentejo Region) and Silves, Faro and Tavira (Algarve Region)

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

A dam has been built in the South of Portugal that is going to allow in the long run for the transition of 110.000 ha of land from dry to irrigated agriculture. This major shift has social impacts, economical impacts and environmental impacts and to deal with the change, an Operational and Technological Irrigation Centre (COTR) was created in 1999, which has amongst other objectives to stimulate the scientific and technical information in the domain of irrigated crops. Following this mandate, COTR has developed several R&D projects and is making an effort to take advantage of ICT potential to build information services to support farmers in their irrigation decisions.

This work presents a Web decision support system which is supported by a network of automatic weather stations. Taking into account user information input (location, soil, crop, irrigation technology and seeding date) it supplies an on-line real time optimal irrigation calendar. It supplies the farmer's real one if the user inputs its own water supplies. The information delivery has multiple output options, namely through the Internet with a web interface or a personal digital assistant and through mobile phone with SMS.

Irrigation scheduling,, through crop evapotranspiration calculation follows FAO Irrigation and Drainage Paper 56 guidelines (Penman/Monteith). The information system is supported by a relational database where the weather station and user data are stored and where information characterizing the region's most common soils, crops and technologies is also kept. This last information is also resulting from other R&D projects undertaken by COTR

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

After the service implementation, farmers believe that they can improve irrigation scheduling of their crops. Every year the number of users is increasing

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

The biggest difficulties are related to the low use of web services by Portuguese farmers (only less than 20% frequently uses the web)

M. Difficulties of the service or information as seen by the farmers concerned

Most farmers don't use web services or only use them for weather forecasts

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Nowadays the service is based on periods of a week. Initially farmers are not receptive to such matters, but after some information or after the first year they are asking for daily information

O. Chances of expanding the application of the improved example

The application has already been expanded to the Algarve Region. The main objective of the service is to reach all regions of Portugal where irrigation is an important agricultural activity

P. Related examples found elsewhere in the Province (or in the country for that matter)

In Portugal there aren't services of this kind. There are such services in many regions of Spain, such as Murcia, Castilla La-Mancha, Andalucia. Also in other countries like USA, in regions such as California, Colorado and Arizona. But none have such strong web components

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

During the first 3 years this work was based in R&D projects with the main objective to calibrate the (FAO) methodologies by comparison with the crop requirements obtained from soil water monitoring

R. Could research assist in improvement of the service/information and how?

At that point, research could assist in the use of new crops or in transfer of the service to other areas, that is to a different reality

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

This kind of services are essential for a good irrigation scheduling, but we can't expect that farmers will use it often by themselves. It is very important to develop an irrigation extension service with technicians prepared to help farmers on this subject, using the required tools. These technicians are connected to COTR, that will help them any time anywhere

[Original submission (2005) edited by Jorge Maia; version for this book edited by Kees Stigter]

[Original submission received second prize in the first INSAM contest (2005)]

II.C.1. <u>*Protocol number CI*</u>

Short name of example:

Advisory and service system of crop and variety planning in Xing'an

A. Country/province where example was found

China, Inner Mongolia AR, Xing'an League

B. Institute providing the example (with address)

Xing'an Meteorological Bureau, 46 Tiexi Beidalu, Wulanhaote, Inner Mongolia AR Inner Mongolian Meteorological Administration, 49 Hailar Street, Huhhohaote, Inner Mongolia AR

C. Researchers that collected/described this example (with the e-mail addresses)

Hou Qiong (qiong_hou@sina.com), Tang Hongyan (wsyythy@sohu.com), Niu Baoliang (nbllbn@163.com)

D. Field(s) of Agrometeorology to which the example belongs:

[Use the fields of interest defined for registration of members of INSAM]

Agro-Climatology (AC), Agrometeorological Indicators (AI), Agrometeorological Services (AS), Data Management (DM), Operational Agrometeorology (OA), PHenology (PH), RIsks in weather and climate (RI), Topoclimatology/Mountain areas (TM)

E. Natural disasters (s) and/or environmental problems to which the example is related

Cold injury, frost and drought

F. Way, in which the example was found, defined and collected

In 2002–2004, the Xing'an (Sub-provincial) Meteorological Bureau was working to refine local climate resources. It found from surveys and discussions with the agricultural sector that in Xing'an there was a tendency to plant corn beyond its suitable areas. This was an unchecked attempt to pursue high yielding varieties with a longer growing period. To address this concern, the Sub-provincial Bureau developed this agrometeorological service. It has become well recognized by the local governments and farmers for its usefulness in guiding them as how to plan and lay out the growth of corn varieties with focused scientific support

G. Farming system(s) in which the agrometeorological service is applied or to whom the agrometeorological service is provided for actual use

Corn monocropping within Xing'an, within the transitional zone between the Great Xing'an Mountains and the Songnen plain, with a geographic layout of higher mountains, low mountains, hills and plains from northwest to southeast

H. Region of the country (countries), where the example can be found

The service system has been installed in Meteorological Bureaus of Keyou Front County, Zalaite County, Tuquan County and Keyou Middle County in Xing'an League, covering such townships as Suolun, Shumugou, Alideer, Dashizhai, Guji and Haoren in the northwestern Keyou Front County, Baoshi, Xuetian, Liuhu and Yong'an in the central and northern Tuquan County, and Bayan Ulan, Xinlin, Alatanhua, Huerle and Bayanzhalaga in the northern and central Zalaite County. They fall all into the semi-arid continental monsoon climate and meso-thermal zone with four distinctive seasons

I. Villages where the examples can be found

The findings of this case study were applied in Bayannur village, Bayannur township, Bayantala village, Bayanmangha township located in Keyou Middle County and the townships of Suolun, Dashizhai, Guji and Haoren located in the northwestern Keyou Front County, in Xing'an League

J. Describe the good example of the operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problems(s) concerned

Corn is the major crop in the Xing'an League, with height differences of grown corn up till a 1,000 m. Its sowing area takes 50% of the total crop acreage of the entire league. Total corn output is around 70% of total crop yields of the league. The frost-free period in rural areas lasts 110–142 days, but north of the mountains it is 59–145 days. Since the heat resources in the Xing'an League vary so significantly from place to place, the corn varieties that are suitable to plant in even two adjacent areas are not the same. At the same time, Xing'an has experienced a warmer and drier climate in recent years. This is to some extent conducive to increasing agricultural production, but also heightens the risks in agricultural production. At present, the pattern of corn varieties is irrational in Xing'an.

Firstly, in the northern area, where the heat resources are insufficient, farmers blindly look for varieties with a longer growing period and higher yields. This causes immaturity of the autumn crop and affects both corn yield and quality, especially in the lower temperature summers or in drier years. Secondly, in southern areas with better heat resources and relatively poorer water resources, farmers often choose crop varieties with shorter growing periods, without using climate resources *appropriately. This is due to limiting production conditions and sometimes to traditional farming practices. Such farming activities lead to unstable crop outputs, preventing increase of economic benefits and farmers' income. In order to make full and rational use of climate resources, Xing'an Meteorological Bureau made a refined agricultural zonation based on its climate resources. The agrometeorological service was established based on this characterization.*

The region of the present service is in a semiarid and rainfed farming area, being exposed to frequent spring droughts. The annual precipitation, especially the amount of spring rainfall and the timing of the first rainfall to moist the soil, has a direct impact on spring sowing and normal growth. Temperature is the primary factor determining the pattern of suitable crop varieties, while water resources and irrigation determine the crop yields.

Therefore, the preliminary study in planning corn varieties mainly focused on heat indicators, in which water resources (irrigation) are only treated as a subsidiary condition. Taking into account in a comprehensive manner both water and heat resources, the arable land was first divided into irrigable flatland, flatland without irrigation and sloping farmland. Subsequently the planting indicators were identified on the basis of heat resources. These indicators could be used to distinguish and identify agroclimatic resources in various villages, so as to choose those varieties that are most suitable for individual localities. Through the system, it is possible to retrieve the major corn varieties and next suitable varieties under different productivities in each individual township or village. Meanwhile, it is also possible to locate those areas suitable/next suitable/not suitable for any new crop varieties, and the system plays a role in planning new crops.

According to the short range climate prediction issued by Xing'an Meteorological Bureau every March and based on available heat and water resources, the crop variety pattern will be adjusted to mitigate the impact of climate fluctuation. The service has played a positive role in guiding farmers and related agencies to select most suitable major corn varieties accompanied with secondary varieties, with certain encouraging economic benefits having been achieved

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increases in income due to the services or information

The first climate advisory service products for the corn variety planning and layout were demonstrated at the Northeast China Agricultural Products Exposition held in Wulanhaote in 2003. It was widely recognized by farmers and seeds providing authorities.. In each spring, based on the crop variety layout provided by meteorological offices, agricultural practice facilitation authorities provide technical guidance by sending technicians to townships and villages, by organizing training courses, through person to person advisory service, by disseminating technical handouts, etc., to ensure that at least one person in each household is aware of the planned crop variety layout.

In 2004–2007, the Xing'an Meteorological Bureau provided advisory services concerning corn zonation and layout planning for over 20 corn varieties, covering more than 40 townships of 5 major agricultural production counties within the whole region. The service priority was given to providing guidance for those farmers with poor production conditions and low management skills. In the context of the early frost in 2006 and droughts in 2007, no substantial reduction of production was suffered, as it happened in previous years. Hence the service benefits were quite evident.

The Xing'an Center for Agricultural Technology Facilitation made trial demonstrations on early sowing of higher yielding and later maturing corn varieties in the southern Xing'an League, with rich heat resources, in 2005. In one case study a proposed change in varieties gave a yield advantage of more than 25% compared to the traditional variety. The economic benefit was nearly 600 Yuanha^{-1}. Under even higher yields in 2006, due to better rainfall, in another case study one new variety introduced gave 20% more yield and another even 165% more.

Agrometeorological information is made available to local governments and agriculture related agencies for incorporation into decision making concerning crop variety planning and layout. For example, an investigation report of this nature was provided to the Xing'an League Administrative Office in 2007. User friendly climate advisory software regarding crop variety planning has been provided to various County Meteorological Bureaus and farming technique facilitators, so that agrometeorologists and agricultural technicians at the grassroots can have the right farming techniques at their finger tips, enabling them to acquire and provide technical services for crop variety planning

L. Difficulties encountered in introduction and use of good example of agrometeorological services or information

The service network is still inadequate. As the agricultural production involves more than one sector and linkages, and the agrometeorological service delivery lacks both human and financial resources, the promotion solely by agrometeorological specialists is limited. It is necessary for other actors, like agricultural technique facilitation bodies, seed services, grass-root weather stations and township meteorological assistants to take part. Support from local governments is required before the applications can be expanded at village and household levels

M. Difficulties of the service or information as seen by the farmers concerned

Farmers are slow to accept new knowledge produced by advanced science and technology. Their mentality features "seeing is believing". Therefore, a facilitation will not be made until an intercomparison is made and demonstrated, which poses a greater difficulty to Meteorological Bureaus, especially those at the grassroot level. It is necessary to rely on leverage by other social actors

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Farmers hope for corn varieties that meet the conditions of heat, water, soil and fertilizer, or a portfolio of cultivation practices. Scientific and technical advisors are expected to offer personal guidance in the fields. The former expectation can be met with relative ease but the latter poses difficulties

O. Chances of expanding the application of the improved example

The present service, which is based on Xing'an's special terrain and climate, is only suitable for that area. The principle of the service, however, can be applied to other areas and crops

P. Related examples found elsewhere in the Province (or in the country for that matter)

Literature shows that many study results on crop zoning are available both at home and abroad. An example is the chestnut suitability distribution developed by the Beijing Meteorological Bureau using refined climate resources. Others are the cultivation and distribution of citrus, kiwi and navel oranges developed by Fujian, Guangdong and Jiangxi Meteorological Adminisrations respectively. However, no service system in support to planning of corn varieties has ever been documented

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

It was developed based on findings of a research project funded by the Inner Mongolia Meteorological Bureau. After preparative visits by Profs. Zheng Dawei (CAU) and Kees Stigter (APMP, Agromet Vision) to Inner Mongolia from 2004 till 2006 and after a visit to this case study with discussions in 2008, we already reported on this service preliminarily in the information sheet:

Stigter K, Niu Baoliang, Yang Song, Hou Qiong, Zheng Dawei, Ma Yuping, Wang Shili (2008) Recent identification of two agrometeorological services in Inner Mongolia Autonomous Region, Northern China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

R. Could research assist in improvement of the service/information and how?

Further research on agrometeorological techniques, zoning indicators and software would be able to improve services. By selecting climatic data from 27 weather stations at the southeast slope of the central Great Xing'an Mountains collected *between 1971 and 2000, and by using GIS data at a scale of 1:250,000, a model was set up to reveal the spatial patterns of both agroclimatic elements and geographic parameters in Xing'an. Based on GIS technology, longitude, latitude and elevation data of townships and villages as well as village-based agroclimatic resources could be determined. All the models have passed significance tests and fitting verifications. Since the rural areas of Xing'an are located at the southeast slope of the Great Xing'an Mountains, where topography is generally homogeneous, no consideration was given to the impact of exposure orientations in the model*

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

At present, agrometeorological information and services are oriented to local governments rather than farmers. An unimpeded access to information by farmers is essential to an upgraded agro-meteorological service. Obstacles in understanding and communication between supply and demand often prevent agrometeorological information from playing its due role. Moreover, under such conditions, services and products become less relevant or useful. Therefore, it is proposed that:

(1) in a critical farming period or under abnormal agrometeorological conditions, there should be physical presence of service providers in the fields from time to time. Based on field fact findings and an analysis of current conditions, advice should be provided to make use of beneficial conditions and to avoid hazards;
(2) in each spring, outreach activities should be conducted in rural areas, during which agrometeorological information and services could be demonstrated. At the same time, the needs of farmers could this way be better understood to facilitate the delivery of tailored agrometeorological services

[Original edited by Xiao Hongxian and collaborators (China Meteorological Administration (CMA), Beijing) from draft Chinese texts by the authors mentioned under C, solicited and collected by Zheng Dawei, Ma Yuping and Wang Shili; the above version was edited by Kees Stigter, using the original, his own mission reports and another English draft translation by Xiao Hongxian and collaborators of a Chinese draft project report by the authors mentioned under C. and solicited and collected again as indicated above. The material given above will after further amendments be used in the near future to draw general lessons on agrometeorological services in China and to validate the present services for future improvements as wanted by CMA.]

II.C.II *Protocol number CII*

Short name of example:

Sowing advice for spring wheat depending on the frost melting condition in the autumn irrigated top soil in Bayannur

A. Country/province where example was found

China, Inner Mongolia AR, Bayannur League

B. Institute providing the example (with address)

Bayannur Meteorological Bureau, No. 5, Xinglong Street, Linhe District, Bayannur, Inner Mongolia AR
Inner Mongolian Meteorological Administration, 49 Hailar Street, Huhhohaote, Inner Mongolia AR

C. Researchers that collected/described this example (with the e-mail addresses)

Hou Qiong (qiong_hou@sina.com), Yang Song (yangsong851230@sohu.com)

D. Field(s) of Agrometeorology to which the example belongs:

[Use the fields of interest defined for registration of members of INSAM]

Agro-Climatology (AC), Agrometeorological Indicators (AI), Agrometeorological Services (AS), Climate Prediction (for Agric.) (CA), Natural Disaster (ND), RIsks in weather and climate (RI), Agrometeorological Statistics (ST)

E. Natural disasters (s) and/or environmental problems to which the example is related

Water logging ("spring tide"), Sub-soil frosts, Salinization, Late frost, Dry hot winds, Increasing pests and diseases

F. Way, in which the example was found, defined and collected

Pre-frost autumn irrigation is essential but due to delays the frost melting condition of the oversaturated soil becomes the determining factor in the possible time for sowing. The resulting "spring tide" period should be known. See also under J and K

G. Farming system(s) in which the agrometeorological service is applied or to whom the agrometeorological service is provided for actual use

Spring wheat monocropping

H. Region of the country (countries), where the example can be found

Linhe City, Hangjinhouqi, Wuyuan County, Wulateqianqi, Dengkou, etc.

I. Villages where the examples can be found

It has been applied to over 1,000 villages in Bayannur City, such as the Dongfanghong Village of Erdaoqiao Town, Hongsheng Town, Tuanjie Town, etc.

J. Describe the good example of the operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problems(s) concerned

When freezing (by mid-November) occurs, late irrigation water is often still on the surface of farmlands in the Hetao area of Bayannur. It can even form an "icy surface". A consequence is that water logging often occurs during the sowing period of spring wheat, because the water can't infiltrate the lower frozen soil. These water logged farmlands are commonly known as "spring tide" lands. Research has learned that it is time for spring wheat sowing when mean daily air temperature reaches −4 °C in the second and last decade of March. The soil surface of farmland is thawing, but deeper soil layers are still frozen. Upward transport of soil moisture makes the water content of the soil surface layer to be saturated, which prevents spring wheat sowing. This can also cause salinization because of upward salt transport. In the past 20 years four severe spring tides took place (1987, 1993, 1997, 2007). In 1987 the agrometeorological service did not yet exist, but the other three cases were successfully combated, with campaigns improving in time.

An appropriate early sowing enhances production and reduces the risks of dry and hot wind that poses threats to wheat filling and maturity stages. This improves yields. According to experiments on different sowing periods, the early sown wheat has a higher yield than late sown wheat (in April). From March, if sowing is delayed, every 10 days the yields would decrease by 10–12%. Damage by dry hot air would be additional. Spring tide lands tend to cause a delay in spring wheat sowing in this area by about 10–15 days (April), which would shorten spiking and filling stages. Generally, the yields of delayed spring wheat may reduce by 750–1,500 kg ha^{-1}. In recent years, the sown acreage of spring wheat in Hetao area is about 150,000 ha, accounting for 35–40% of the total sowed area of crops. The area affected by spring tide is about 50%. Therefore, spring tide is a major disasters that prevents spring wheat yield improvements in this area.

If the irrigation practice remains basically unchanged, the weather conditions after irrigation would determine, to a large extent, the timing and severity of the spring tide. Meteorological and other factors for occurrence of the spring tide have been determined by correlative analysis. By using regression analysis, forecasting equations were established to identify the timing and intensity of the spring tide as *well as a suitable sowing date for spring wheat. The major determining factors for the occurrence of the spring tide are the rate of temperature rising in March, precipitation, wind direction and air humidity in March, the depth of frozen soil, and the irrigation status in October and November of the previous year. By comparing the weather conditions in the current year with multiyear mean values, it tells if these weather conditions are conducive to the spring tide. More complicated regression formula were developed for forecasting the timing of the spring tide within March, for the medium and long range forecasts of the intensity of the spring tide, and for forecasting of the sowing date, again in March.*

Measures for spring tide prevention and yield increase include: (1) in a normal year, the sowing of spring wheat begins as from 5 March, climaxing on 15 March. After the occurrence of spring tide, sowing period should be appropriately adjusted, taking into account the soil moisture; (2) sowing starts in the fields on the river sands and in wetlands, then come the fields at higher lands; it also goes from sandy soil to clay soil; (3) if soil moisture is high, sowing should begin as soon as it is possible to prepare fields, dry or adjust soil moisture, and sow at an earlier date as otherwise appropriate; if the soil moisture is lower, it should be preserved by all means and sowing should start according to appropriate soil moisture, to ensure seed germination.

Information is delivered to local government leaders, agricultural professionals and related agencies both in written and electronic formats. The delivery process within the meteorological establishments is from the Bayannur Meteorological Bureau to County Meteorological Bureaus, eventually to the township governments and information disseminating staff. The delivery beyond the meteorological community goes on from local governments at all levels to relevant users, combined with specific farming related activities, following the top-down administrative procedure. Substantial economic benefits have encouraged a larger number of farmers to make use of agrometeorological information

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increases in income due to the services or information

Information is delivered through field meetings. Each year, according to the sowing period and the spring tide forecasts from the Meteorological Bureau, governments at all levels will choose typical spots to hold on-the-spot meetings. Here meteorological professionals will tell farmers about the spring tide, when it occurs, suitable sowing time, recent weather trends and measures and sowing advisories, so that farmers have direct access to weather information related to the sowing. Forecasts are issued to relevant bodies and farmers in the first decade of February in written form such as agrometeorological information, bulletins and circular letters. Also mass media including radio broadcasting, internet, mobile phone messages and village loudspeakers are used. Afterwards, updated forecasts will be issued in a timely manner, focusing on the weather changes at any time and future weather. At the *same time, measures for spring tide reduction and relevant production advisories are also proposed.*

After the information is issued, agricultural information delivery staff from various townships (sent by agricultural units) will go to farmers or hold on-the-spot spring wheat sowing meetings to further promote and guide the sowing activities. They will also deliver specific production advices and responsive actions when the proven farming techniques for early sowing and yield increase are applicable. After preliminary attempts made at forecasting in the early 1990s, it became popular. Through investigations of feedback at the grassroot level, it was found that the spring tide forecast is wanted by local governments and farmers

L. Difficulties encountered in introduction and use of good example of agrometeorological services or information

What we have provided is a public service, but it is difficult to get feedback and to make quantitative evaluations of the effectiveness of this agrometeorological service

M. Difficulties of the service or information as seen by the farmers concerned

It is difficult to organize those farmers with less education that farm in a decentralized manner. This has inhibited the effectiveness of the service to some extent

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Farmers hope for more accurate and timely forecasts and more preventative measures. The forecasting methods need to be improved. Field experiments and research should be strengthened, in order to improve forecast accuracy and validity and to find better measures for hazard prevention or hazard reduction. Late spring frost and increasing pests and diseases may need further studies

O. Chances of expanding the application of the improved example

The current service is likely to be promoted in those areas affected by the spring tide in Tumochuan Plain, Northeast Irrigation Area, etc., and there is room for improvement

P. Related examples found elsewhere in the Province (or in the country for that matter)

In cold and humid areas in winter, if it gets warmer quickly in spring, the spring tide occurs but its severity and impacts are different

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

No formal research project was established, but the conclusions from the statistical analyses on the basis of operational requirements demonstrated its scientific value. After preparative visits by Profs. Zheng Dawei (CAU) and Kees Stigter (APMP, Agromet Vision) to Inner Mongolia from 2004 till 2006, and after a visit to this case study with discussions in 2008, we already reported on this service preliminarily in the information sheet:

Stigter K, Niu Baoliang, Yang Song, Hou Qiong, Zheng Dawei, Ma Yuping, Wang Shili (2008) Recent identification of two agrometeorological services in Inner Mongolia Autonomous Region, Northern China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

R. Could research assist in improvement of the service/information and how?

Searching for impact factors, providing forecasting methods and improving forecasting accuracy could be researched

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

Agrometeorological information is a primary decision-making basis for guiding farmer's production, hazard prevention and hazard mitigation. Strengthening agrometeorological information services and disseminating the information directly to farmers in a timely manner will enhance the effectiveness of the services and the income of farmers; it can also identify issues for further studies, so as to improve the quality of agrometeorological services and its social recognition

[Original edited by Xiao Hongxian and collaborators (China Meteorological Administration (CMA), Beijing) from draft Chinese texts by the authors mentioned under C, solicited and collected by Zheng Dawei, Ma Yuping and Wang Shili; the above version was edited by Kees Stigter, using the original, his own mission reports and another English draft translation by Xiao Hongxian and collaborators of a Chinese draft project report by the authors mentioned under C. and solicited and collected again as indicated above. The material given above will after further amendments be used in the near future to draw general lessons on agrometeorological services in China and to validate the present services for future improvements as wanted by CMA.]

II.C.III *Protocol number CIII*

Short name of the example:

Improving microclimate for water melon by covering sandy soil with pebbles

A. Country/Province where the example was found

China, Ningxia Hui Autonomous Region

B. Institute providing the example (with address)

Ningxia Meteorological Research Institute, Ningxia Autonomous Regional Meteorological Bureau, 199, Xinchangxi Road, Yinchuan City, Jinfeng District

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Liu Jing (ahmd_liujing@163.com), Zhang Yulan (zhang yulan_111@126.com)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agrometeorology and Development (AD), Agrometeorological Services (AS), Crop Micrometeorology (CM), DRought (DR), RIsks in weather and climate (RI), Operational Agrometeorology (OA), User's Needs in agrometeorology (UN)

E. Natural disaster(s) and/or environmental problems to which the example is related

Agricultural drought; Shortage of water resources

F. Way, in which the example was found, defined and collected

Pebble-covered sandy soil watermelon production practice can be traced back to more than a century. In recent years, through multiple investigations with the melon-growing farmers, the Provincial Meteorological Bureau found that the key factor in low and instable watermelon yields was the microclimate

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use.

Watermelon production systems

H. Regions of the county (or counties) where the example can be found.

At present, the pebble-covered sandy soil watermelon growing areas are mainly distributed in the region surrounding Mt. Xiangshan within the Zhongwei City Region, including Xingren township in northern Haiyuan county, Hanjiaoshui (Crying for Water) township to the west of the Tongxin county, and the eastern side of Mt. Niushou (Cow's head) in the eastern part of the Zhongning county. The total watermelon growing acreage in this region is up to 67,000 ha

I. Villages where the example can be found

In most townships and villages of the mountainous areas under the administrative jurisdiction of the Zhongwei City Region, Xingren township of northern Haiyuan county, including its neighboring villages, bare lands in the eastern Zhongning county, Hanjiaoshui township and northern part of the Hongsibao (Red Mosque Castle) township

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

The so-called "pebble-covered sandy soil watermelons", nicknamed "Gobi watermelons" or "watermelons grown from stones", are produced on dry sandy soils covered with about 10 cm of pebbles collected from river beds. This appears to satisfy their heat and moisture requirements. In these (semi-)arid areas with largely late summer and autumn rains, this farming practice enhances water infiltration and reduces the evaporation of soil moisture and water run-off. Generally, the soil moisture under the pebbles is kept above 8%, supplying sufficient water for healthy watermelon growth, while under the same local climate conditions, the uncovered soil has soil moisture below 6% in spring time of most years, which is insufficient to keep the plants alive. In uncovered soil, in spring the soil can be dry till half a meter depth.

The pebble mulch also causes a soil temperature which is desirable to grow drought resistant species of watermelons and other cash crops. It was found that pebble covered surface temperatures are higher at daytime and lower in nighttime, due to the insulating stone mulch. This larger temperature range is highly favorable for sugar accumulation within the fruits. Early sowing is essential because of the shortage of the growing season.

Local farmers normally need to water and sow in individual holes. The seeds are brought into such holes in the layer of pebbles that remain a cavity over which a cup is brought, or a piece of plastic film covering a larger area. They are irrigated at the seedling stage. Then all they have to do is to wait until the rainy season comes. The groundwater is several hundred meters deep, mostly brackish, that can not be used for water replenishing. In some cases, farmers have to transport water from dozens of kilometers away, and the cost is obviously very high. Therefore, the annual rainfall and drought predictions are the key factors in making appropriate arrangements *for water replenishing in terms of both timing and quantity, to increase production and economic benefits, and to reduce unnecessary inputs and costs.*

Pebble mulched sandy soils additionally covered (in part) with plastic film can further enhance soil moisture and temperature of the planting hole. While evaporation is locally blocked by the plastic, the rain water still permeates into the soil from around the watermelon seedling. Investigations show that the soil moisture of a growing site extending 30–50 cm beyond the planting hole covered with a piece of plastic film proves to be 2.0–3.5% higher than that without a plastic film. It has been measured that at the bottom of such covered cavities, the soil temperatures can be in the order of 5° higher than near the pebble surface.

It was found that soil surface temperature is most effective when each seedling is covered with a plastic cup, which can be repeatedly used. In lower temperature years, when frosts are more frequent, the cup covering practice is more effective in conserving soil heat, protecting the watermelon seedlings from frost, and promoting growth. But this practice is only limited to smaller acreages as the field practice is labor intensive and therefore costly.

Since 2004, the Ningxia AR has promoted this practice for poverty alleviation in the mountainous areas, with growing areas being quickly expanded, and with products selling to more than 30 cities across the country and even overseas. About 150,000 poor farmers in the mountainous regions rely on the watermelon production, with the annual income being noticeably increased. Since 2005, the specialized agrometeorological service for decision making in watermelon production has been provided to city governments.

A "special meteorological bulletin on pebble covered sandy soil watermelon production" has been prepared on a regular basis, which provides monitoring facts and analysis on soil moisture for watermelon growth in double mulched farming practices. Dynamic soil moisture monitoring outcomes are made available to local agencies on a decadal basis. Moreover, response strategies are proposed for agricultural production management, according to the recent weather forecasts in conjunction with the growth status of the watermelon under such cultivation practices

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

The watermelon yield under traditional cultivation practice is normally just below 50,000 kg ha^{-1}, and in cases of extremely dry years, it might be a complete failure. The yield adopting the double mulched (pebbles cum plastic) cultivation technique is generally 20 till 30% higher than in the traditional pebble covered farming. The net economic benefits are 300 & just below 3,000 Yuanha^{-1} more than those in only bowl covered practice and in bare sandy farmlands respectively.

The dedicated agrometeorological service covers the following aspects: Firstly, in combination with the long range weather forecasts, such forecasts and services are provided as (i) most appropriate sowing modalities, (ii) favorable sowing period, (iii) ripening period, including (iv) analyses of meteorological conditions *prone to diseases and pests, etc., thus reducing the production risks. Secondly, decision making oriented agrometeorological services are rendered in case of severe drought years, which can play a substantial role in organizing widespread combating of drought, saving the seedlings and minimizing the damages.*

For example, in 2006 the central arid zone in Ningxia witnessed a severe drought, according to the soil moisture monitoring from 20 sites. Considering the fact that water availability from the Yellow River was rather limited, the Meteorological Bureau indicated that the drought was severe and seedlings would massively wither soon. According to the longer range weather forecasts, the drought would persist in the forthcoming period. It was proposed to the local governments and decision making bodies that it would be an illusion to wait for rain. Irrigation had to be provided by tapping nearby water resources as much as possible and priority should be given to the areas where the soil moisture was critically poor. Eventually, the local government adopted the advice from the Meteorological Bureau, special funds were allocated to subsidize the water transportation costs and irrigation water expenses, and even fire engines were called for to bring the "life-line" water to individual planting holes. Eventually, the 44,000 ha of watermelon were saved, preventing a potentially complete crop failure.

Furthermore, based on the demands for the Gobi watermelons from more than 30 large or medium-sized cities across the country, specialized weather forecasts of the relevant watermelon consumption cities have been also provided for arranging commercial activities

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

The agrometeorological studies on scientific issues concerning the pebble covered sandy soil watermelon farming are rather limited. So far neither quantitative nor qualitative indicators have been established in revealing the relationship between the watermelon growth and microclimatic and soil moisture conditions, etc. Therefore, there is lack of solid science based evidence for providing agrometeorological services. Service products and materials are therefore less persuasive than they could be. Advisories are less operational than they could be, thus being in a difficult position to satisfy all demands of local decision makers and watermelon growers

M. Difficulties of the service or information as seen by the farmers concerned

Due to the poverty of watermelon growing farmers in the central arid region of the Ningxia AR, their ownership of mobile phones is still quite limited. On the other hand, the telecommunication conditions are underdeveloped in the remote mountainous area. Without cable TV, the farmers living in these areas cannot get access to TV programmes dedicated to rural areas. Therefore, the channels to get access to useful agrometeorological information by these farmers are rather limited. At present, the service is mainly delivered to the grassroot agricultural technicians and farmers through local governments and agricultural bodies at various levels, *in order to guide them in adopting scientific farming practices and in agricultural disaster prevention and mitigation. Due to limited resources, it is impossible to conduct an overall survey on the economic benefits from the services covering all watermelon growing areas, which can only be roughly estimated according to the relevant statistics provided by the local governments.*

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Improvements may be envisaged as:

(1) the melon growing farmers wish to get access to agrometeorological service products with additional information to address such issues as protection of seedlings from drought, frost prevention, watermelon wilt and decay, etc.;
(2) The farmers are looking forward to receive timely information. For the time being, due to limited and indirect information channels, some farmers do not even know when frost may occur even when it is forthcoming. It may be too late to take any preventative measures when it comes, causing a widespread loss of seedlings;
(3) The farmers badly need relatively longer range weather forecasts and price information about various markets, in order to arrange appropriate sowing periods well in advance, and to establish links to sale channels, hoping to achieve a good harvest.

From the perspective of service delivery, the future objectives are to increase service coverage and information, expanding the agrometeorological services and products targeted to the pebble covered sandy soil watermelon production

O. Chances of expanding the application of the improved example

Up to now, the service delivery is limited to the region surrounding Mt. Xiangshan of the Zhongwei City Region. With the further expansion in terms of watermelon acreage into the northern Haiyuan county and areas around the Zhongning county, services should cover all these areas, with more information and products being made available as scientific research goes more in depth

P. Related examples found elsewhere in the Country (or Countries for that matter)

The pebble covered sandy soil watermelons are also grown in the areas east of Lanzhou City, Gansu province. Along with the increased plantings for many years, the soil fertility gradually decreases to an exhausting status, with yields per hectare continuing to decrease year by year, while the scale of planting also continues to shrink. At present, the dedicated agrometeorological service for the watermelon growers is limited to Ningxia A.R. Considering that the same practice is also adopted in neighboring Gansu province, some thoughts will be given to extend the current services to be made available in Gansu province in the future

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

The agrometeorologists in the Ningxia AR began to monitor the soil moisture of the pebble-covered sandy lands, and to investigate the growth stages of the watermelon crops, including yields and their relationship with soil-moisture dynamics. With this base they have established indices of crop resistance to drought and water replenishment. These findings have been applied to the agrometeorological services targeted to watermelon production in pebble covered sandy lands.

Subsequently, intensified microclimatic observations and crop growth measurements have been organized, to study the effects of moisture conservation and temperature increase with different mulching modes. On the basis of these in-situ observations, models have been developed to predict the watermelon yields and ripening periods around the Mt. Xiangshan region. The impacts of major adverse agrometeorological events on the crop growth and production have been investigated, according to which zonation desirable for pebble covered sandy soil watermelon farming has been proposed for the autonomous region.

The pebble covered sandy soil watermelon farming is a planting practice developed in farmer experiments by the local farmers through their long term farming responses to arid farmland conditions. However, these research results have not been written up. The agrometeorologists provide their dedicated services based on these farmer experiences and their own (still limited) research findings. In the years 2004–2008, Profs. Zheng Dawei (China Agricultural University) and Kees Stigter (APMP, Agromet Vision) learned about the system while visiting it and discussing it with Prof. Liu Jing. We reported on this preliminarily in:

Stigter K (2006) Agrometeorological services in various parts of the world, under conditions of a changing climate. Austin Bourke Memorial Lecture presented in the Royal Irish Academy, Dublin, in the evening of 2 March. Extended Abstract available on the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology" of March 2006

Stigter K, Liu Jing, Zheng Dawei, Ma Yuping, Wang Shili (2008) Further identification of two agrometeorological services in Ningxia Autonomous Region, Western China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by C.J. Stigter. WMO, Geneva, in press

R. Could research assist in improvement of the service/information and how?

We could propose research on (i) the influence of soil moisture stress in pebble covered sandy soil watermelon growth, development, and yield; (ii) changes of nutrient levels in the soil, in which the watermelon is grown for many years, by measuring nutrients and microbial activities in the soil in different periods of time;

See also under L Remote sensing technologies used to monitor soil moisture in the watermelon fields, may become one of the approaches for improving the current services

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

It would be necessary to actively explore new channels of agrometeorological services and information for farmers, so that relevant information can be timely delivered to farmers

[Original edited by Xiao Hongxian and collaborators (China Meteorological Administration (CMA), Beijing) from draft Chinese texts by the authors mentioned under C, solicited and collected by Zheng Dawei, Ma Yuping and Wang Shili; the above version was edited by Kees Stigter, using the original, his own mission reports and another English draft translation by Xiao Hongxian and collaborators of a Chinese draft project report by the authors mentioned under C and solicited and collected again as indicated above. The material given above will after further amendments be used in the near future to draw general lessons on agrometeorological services in China and to validate the present services for future improvements as wanted by CMA.]

II.C.IV *Protocol number CIV*

Short name of the example:

Forecasting fungus disease conditions for wolfberries

A. Country/Province where the example was found

China, Ningxia Hui Autonomous Region

B. Institute providing the example (with address)

Ningxia Meteorological Research Institute, Ningxia Autonomous Regional Meteorological Bureau, 199, Xinchangxi Road, Yinchuan City, Jinfeng District

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Liu Jing (ahmd_liujing@163.com)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

Agrometeorological Services (AS), Agrometeorological Indicators (AI), Crop Micrometeorology (CM), Crop Protection (CP), Early Warning and monitoring (EW), Operational Agrometeorology (OA), Pests and Diseases (PD), Weather Forecasting (for Agric.) (WF)

E. Natural disaster(s) and/or environmental problems to which the example is related

Crop disease

F. Way, in which the example was found, defined and collected

In studying the climatic zoning of high yielding and high quality wolfberry production, through experimental observations and investigations with wolfberry growers it was found that a fungus disease of wolfberry, Anthracnose, had serious implications

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use.

Wolfberry production systems

H. Regions of the county (or counties) where the example can be found.

Most counties in Ningxia's wolfberry producing area, such as Pingluo, Zhongning and Zhongwei counties

I. Villages where the example can be found

Wolfberry Anthracnose is now timely controlled according to early warning information in most parts of Ningxia, including most villages and towns under the jurisdiction of Zhongwei City, all villages and townships of Zhongning and Changshantou Farmland, Luhuatai and Nanliang Farmland of Yinchuan City, Huinong District of Shizuishan City, and some villages/townships of Pingluo

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

*To develop the agrometeorological service, the following knowledge was collected. Although wolfberry (***Lycium barbarum L***.) is harvested throughout the growing season that the fruits appear, in the period mid June to July inclusive the harvest is most abundant and 70% or more is collected during that period. The determination and forecasting of suitable conditions for diseases is therefore most important during that period. The Anthracnose of Barbary wolfberry called "black spot", is a severe fungus disease caused by the pathogen* **Colletotrichum gloeosporioides Penz***, which poses great threats to both wolfberry yield and quality. In fields, it takes about 4–6 days from spore invasion to fruit infection. Quite often, summer thunderstorms are associated with wind. When swings of wolfberry stalks scratch the fruits and other plant parts, the splashing of rain water facilitates infections and aggravates the disease. In a severe disease hit year, the percentage of diseased fruits leads to a loss of 50% in production, the market price dropping sharply due to inferior fruit quality.*

Meteorological conditions play a key role in the occurrence and development of this fungus disease. In the western arid areas of Ningxia, where there are more sporadic rainfalls, as long as leaves of the wolfberry plant stay sufficiently wet for more than 6 h, the invasive fungus disease infection is already likely to occur. For example, a larger scale rainfall that persists for a longer period could give rise to outbreak of the disease.

According to weather forecasts, preventative measures can be taken in advance to control the occurrence, development, spread and severity of the disease, hence being in a better position to reduce the potential losses. If the period before and during the peak of the harvest is rather dry, the infestation is often low and no warnings are issued. Wolfberry leaves that stay wet for a certain period are the critical factor for invasion of pathogenic spores. However, when daily maximum temperature is above 40 °C, the vitality of the fungus spores will decline sharply. Temperature beyond 45 °C kills the spores.

The temperature favorable for the fungus pathogen ranges from 22 to 31 °C. At 22–34 °C, the pathogenic spore germinates in 6 h, and spore production is most *active at 22–25 °C. It is also found that the fungus pathogen of Barbary wolfberry has a more strict demand for humidity. When RH is 90%, spores germinate rapidly; and when RH is below 60%, the spore germination is basically terminated. Continuous sunshine favors mycelium growth and spore generation.*

The longer an above 90% relative humidity extends, during which the mean temperature becomes higher, the more invasive the fungus disease will be. When the mean air temperature is above 22 °C, with maximum temperature exceeding 28 °C, germination rates are high. Under such conditions, when both leaves and fruits are wet for over 6 h, or when the rainfall is 5–10 mm, then a slight fungus disease is likely to occur. When at these temperature conditions the rainfall is above 10 mm or continues for more than 6 h, the field transmission of the disease will be more significant. As the rainfall exceeds 20 mm or rain persists for more than 12 h, still with favorable air temperature, it is more likely to witness a wider spread of the fungus decease in the fields. The infection rate may exceed 50%. If the rainfall is around 40 mm for that same duration criterion, the fungus disease of the wolfberry will break out epidemically. Now 50–80% of fruits will be affected or turn black.

With the above often determined from growth chamber research experiments, weather monitoring was carried out, forecasting and warning models were created, and comprehensive preventative and control techniques were identified. The severity of the epidemic disease is divided into 5 categories, according to field epidemic status, to identify the indicators of the fungus disease in development stages. Since 2006, these findings have been put into operational use, issuing trend forecasts and nowcasts. Early warnings about the occurrence of the fungus disease have been provided to decision makers. In collaboration with the County TV, the wolfberry administrative authority of the county published the practical use of specific chemical dosages and mixtures as well as implementation schemes. These timely agrometeorological information and response advisories play a substantial role in controlling the disease. With these efforts, the farmers' economic losses due to the disease have been significantly decreased

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

Barbary wolfberry is used as a famous traditional Chinese herbal medicine and a product that proves to be good for human health. The Ningxia AR is the most ancient and original place of the wolfberry. It has become a well known green commodity as unique local specialty of the autonomous region. The medicines and healthy products made with extracts from the wolfberry fruits account for over 70% of the total domestic markets, and they are exported to Europe, North America, Japan, Korea and Southeast Asian countries, being popular both at home and abroad.

The Agrometeorological Service Centre affiliated to the Ningxia Provincial Meteorological Bureau (Administration) mainly focuses its wolfberry oriented services on weather forecasts of the fungus disease, including short range meteorological warnings and nowcasts. Since 2006, meteorological conditions favorable for the *outbreak and spread of the fungus disease of wolfberry crops have been monitored annually.*

Among others, the forecasts and warnings are delivered to local governments, relevant agencies and farmers in forms of short range agrometeorological bulletins, thematic reports and materials that are prepared on a timely basis in support to decision making on combating the disease. The agrometeorological information is also made available through mass media like Ningxia Agricultural Website and mobile phone SMSs.

Although no meteorological conditions favorable for occurrence of wolfberry fungus decease were detected in 2008, as a "business as usual", the predictions on the trend of the fungus disease and the risk category forecasts were provided on a regular basis. Moreover, agrometeorological forecasts of the optimal fruit harvesting period have been issued operationally for three consecutive years.

The agrometeorological forecasts or warnings on occurrence and wider outbreak of the Anthracnose disease of wolfberry crops are accessible to production managers at various levels 1 week ahead, which enable them to take joint preventative or control actions in a timely manner.

For the wolfberry producers and managers, actions taken 1 week before the disease may occur, control both occurrence and spread of the adverse event, improving the quality of the fruits as much as possible, minimizing yield loss, and maximizing direct benefits from the disaster prevention and reduction efforts.

By visiting wolfberry growing farmers, it was found that they have benefited from early warnings on the outbreak of wolfberry fungus disease. Taking into account the economic loss due to the price fluctuations caused by the fungus disease of wolfberry, a potential loss of about 540 million Yuan was avoided in 2006 in Ningxia's wolfberry production, achieving significant economic benefits from the disaster prevention and reduction measures

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

There are some difficulties in the implementation of the project:

(1) according to the terms of reference of agencies, information on monitoring and forecasts of crop diseases and pests should be issued by agricultural technology promotion and plant protection departments. The Meteorological Bureaus can only issue grade forecasts of weather conditions for possible outbreak of the wolfberry fungus disease;
(2) due to the fact that it is impossible to conduct field investigations with all farmers in the whole region after hazard occurrence, the benefit from the hazard prevention and reduction services can only be roughly estimated, based on the prices and yields of wolfberry

M. Difficulties of the service or information as seen by the farmers concerned

Although most wolfberry growing farmers have television or mobile phones to receive information, they generally don't watch or subscribe to weather service information. The important information about "early warning of wolfberry fungus disease" could be released via mobile phones across the region. However, because of cost constraints, these means can not be used for delivering conventional weather services for wolfberry growers.

Farmers' awareness for adapting to new knowledge and products from advanced science and technology is rather weak. In addition, they also suspect the authenticity of early warning information received via mobile phone. Generally, disease control and timely wolfberry harvesting are conducted only after the information was confirmed by local agricultural and plant protection departments, thus leading to losses due to delays

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Farmers do hope that the weather service for wolfberry will be expanded to include the outbreak of major production pests such as wolfberry aphid and gall midge. Moreover, they urgently need accurate short-term weather forecasts in order to avoid losses in the chemical control of the fungus disease, wolfberry harvesting and drying. The future goal is to expand the range of relevant weather services for wolfberry. However, due to limited resources, it is difficult to achieve this goal shortly

O. Chances of expanding the application of the improved example

At present, the major wolfberry producing areas in the whole region are covered by the dedicated weather services. Because the agrometeorological indicators reflecting the severity of the wolfberry fungus disease are derived from experimental results, they can be widely applied and promoted to major wolfberry growing areas in Xinjiang AR, Inner Mongolia AR and Hebei province

P. Related examples found elsewhere in the Country (or Countries for that matter)

Inner Mongolian Agricultural and Pastoral University has studied wolfberry fungus disease in the Hetao region of Inner Mongolia, and a statistical relationship between wolfberry fungus disease and precipitation has been identified. However, it is still in the stage of research, without being transferred into any operational agrometeorological service. Currently, such services for wolfberry are carried out only in Ningxia AR

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Starting from isolation and identification of the anthracnose pathogen, through experiments from 2003 onwards in climate controlled growth chambers, the biochemical properties of the fungus pathogen under the meteorological conditions were identified. This included the invasive infection of the black spot into the different organic components of a wolfberry plant.

Then, through field plant inoculations of the pathogen, experiments were carried out to simulate the occurrence of the disease under different weather conditions, including precipitation intensity, rainfall amount, air temperature and sunshine duration. This way field infectious processes of fungus disease were investigated, including its occurrence and widespread outbreak. Relevant meteorological indices were this way established.

In 2003, the Ningxia Meteorological Research Institute carried out a study on agrometeorological forecasting methods for the occurrence, outbreak and prevalence of wolfberry fungus disease in Ningxia, under the auspices of the Ministry of Science and Technology.

Analyses were made of correlations between the epidemic indicators of the fungus disease of wolfberry and the meteorological factors available 40 days before the outbreak of the disease, in order to investigate the biophysical mechanisms, and to establish the optimal regression equation that reveals the correlation between the epidemic indicators and the meteorological conditions.

In 2007, a project of overall weather services for wolfberry diseases and pests was supported by a New Technology Promotion Fund of the China Meteorological Administration. A series of research findings have been achieved, based on which relevant operational agrometeorological services are delivered.

In the years 2004–2008, Profs. Zheng Dawei (China Agricultural University) and Kees Stigter (APMP, Agromet Vision) studied the system while visiting it and discussing it with Prof. Liu Jing. They could make use of

Liu Jing (2008) Research on effect of the meteorological environment on germination and expansion of anthracnose of Lycium barbarum L. in Ningxia Autonomous Region. Ningxia Provincial Meteorological Administration, Yinchuan (in Chinese with English Abstract, graphs and tables), 53 pp

We reported on this agrometeorological service preliminarily already in the information sheet:

Stigter K, Liu Jing, Zheng Dawei, Ma Yuping, Wang Shili (2008) Further identification of two agrometeorological services in Ningxia Autonomous Region, Western China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

R. Could research assist in improvement of the service/information and how?

Future goals are to transfer more research findings into operational services. Such findings are related to (monitoring and forecasting of) (i) quantitative indicators, *(ii) correlations of wolfberry growth, development, yield and quality with weather and soil factors, (iii) suitability zonation for wolfberry growing in northern China, (iv) meteorological indicators of dry and hot wind hazards to wolfberry as well as (v) comprehensive control techniques.*

It is necessary to study the relationship between the severity of wolfberry aphid and gall midge infestations, to improve the meteorological monitoring and forecasting system for wolfberry diseases and pests, and to enhance the capacity of comprehensive agrometeorological services for wolfberry production

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

Clarify the linkage with other agencies like in agriculture, forestry and plant protection. Communicate and coordinate with the latter authorities in particular. Seek the understanding of the Ningxia Plant Protection Station, and its consent to the joint issuance of information so that better wolfberry fungus disease warnings can benefit a greater number of recipients

[Original edited by Xiao Hongxian and collaborators (China Meteorological Administration (CMA), Beijing) from draft Chinese texts by the author mentioned under C, solicited and collected by Zheng Dawei, Ma Yuping and Wang Shili; the above version was edited by Kees Stigter, using the original, his own mission reports and another English draft translation by Xiao Hongxian and collaborators of a Chinese draft project report by the author mentioned under C and solicited and collected again as indicated above. The material given above will after further amendments be used in the near future to draw general lessons on agrometeorological services in China and to validate the present services for future improvements as wanted by CMA.]

II.C.V *Protocol number CV*

Short name of example:

Refined agroclimatic zoning used for planning and growing navel oranges, and protection advisory services after planting

A. Country/province where example was found

China, Jiangxi and Henan Provinces

B. Institute providing the example (with address)

Jiangxi Provincial Research Institute of Meteorological Sciences (Jianxi Provincial Meteorological Administration), No.109, Bei'er Road, Nanchang City, Jiangxi Province

C. Researchers that collected/described this example (with the e-mail addresses)

Li Yingchun (jxnclyc2003@tom.com)

D. Field(s) of Agrometeorology to which the example belongs:

[Use the fields of interest defined for registration of members of INSAM]

Agro-Climatology (AC), Agro-Hydrology (AH), Agrometeorological Services (AS), Data Management (DM), Remote Sensing and GIS (RS), Topoclimatology/Mountain areas (TM)

E. Natural disasters (s) and/or environmental problems to which the example is related

Severe cold events (extreme minimum temperatures); dry cold storms (early in the season); cold wet weather with much snow; drought (early and middle season); high temperatures, heavy rainfall (later in the season)

F. Way, in which the example was found, defined and collected

In 2001, navel orange producing areas in the southern Jiangxi were designated by the Ministry of Agriculture as a special citrus production zone in China. In 2002, the Government of Ganzhou City decided to accelerate the development of navel orange industry in Gannan (southern Jiangxi). Based on this decision, it was planned to expand the navel orange growing acreage up to 2 million mu (130,000 ha) with an annual production target exceeding 1 million tons by 2010; and 3 million mu (200,000 ha) targeted to over 2 million tons by 2015. In order to meet these development targets, the Meteorological Bureaus have launched a detailed agroclimatic *zoning campaign using the so-called 3-in-1 technology (GIS, GPS and RS). At he same time, they are active to deliver weather services to authorities concerned at city, county and township levels and to navel orange farmers. These tailored services are an important contribution to layouts and site selections for navel orange plantations and for the preparedness of growers for meteorological disasters (see under E) once the trees have been planted and produce oranges*

G. Farming system(s) in which the agrometeorological service is applied or to whom the agrometeorological service is provided for actual use

Navel orange plantations

H. Region of the country (countries), where the example can be found

Xinfeng County, Longnan County, Xunwu County, Anyuan County in Ganzhou City Region, Jiangxi Province

I. Villages where the examples can be found

The villages and farmers growing navel oranges obtain meteorological information via agents (e.g. fruit industry association) as in Dongjiang village in Longnan County, Anxi and Jiading villages in Huangsha and Xinfeng County, etc.

J. Describe the good example of the operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problems(s) concerned

In China, citrus is cultivated in subtropical and tropical regions. It grows in warm and humid conditions and is temperature sensitive. When a winter cold wave comes from the north, temperature in subtropical China tends to drop sharply. In a severe year, such a cold event could lead to citrus injury. The subtropical region is complicated with hilly and mountainous terrains. Slopes with different orientations and altitudes vary in heat and moisture. Using GIS technology plus remote sensing, the current land uses can be identified for agroclimatic characterization in high resolution, which zonation serves as guidance to farmers in site selection for citrus plantations, using the advantages of terrain based microclimate while avoiding its disadvantages.

Navel orange has a high demand for heat. The annual cumulative temperature ($\geq$ 10 °C) ought to be above 5,500 °C, with the annual average temperature above 15 °C, multi-year averaged extreme minimum temperature above −5.0 °C, sunshine duration in April–November $\geq$1,100 h, and annual average precipitation $\geq$1,000 mm. Among them, the annual cumulative temperature ($\geq$ 10 °C) is the factor that determines the normal growth, development and fruiting of citrus while the multiyear averaged extreme minimum temperature is the threshold for the survival of the citrus plants.

Sunshine duration relates to fruit quality while precipitation is partially decisive for both yield and quality, so they co-determine the suitability gradation (most, rather or just suitable). Across Gannan, both precipitation and sunshine at any altitude or landform meet the simple suitability criteria. However, the cumulative temperature and extreme minimum temperature do not. Therefore, cumulative temperature and extreme minimum temperature are identified as prevailing indicators for citrus plantation zoning. The result is that no citrus is grown any more above 500 m, while most suitable areas are below 300 m. There are this way three larger corridors identified in the north of the County that appeared suitable and a small area in the center north of these areas that appeared very suitable.

Meteorologists at provincial and city levels co-produce a detailed navel orange zoning map for the cultivation at three levels of city, county and township with detailed comments that are made for the government authorities, agriculture and fruit regulators in particular. According to this zoning, government authorities make a decision on navel orange distribution, guiding plantation owners and general farmers in the choice of cultivation sites and preparedness for meteorological disasters. Based on the zoning, meteorologists make a necessary on-site visit to provide growers with more specific and more direct agrometeorological services.

Indeed, another part of this case study are advisory studies related to protection from bad weather and diseases. Irrigation with impounded water, that can be seen available everywhere, is generally done as protection to cold (in dry weather) and to drought. Fire and related smoke can be used for protection from a forecasted late spring or early autumn frost. In rarer years with cold wet weather, actively shedding snow or knocking ice off branches and covering young trees with straw or using it at the base helps, but it occurs less because of the planning from the earlier discussed mapping.

Weather forecasts are also given if weather is too windy for spraying. For all operations, forecasts are given when adjustment from normal procedures is advisable. Protection for storage is also an important subject. It happens in the ground or with pine branches in layers. In Xinfeng there is "on the tree" storage for 8 months, using early, normal and late varieties to make this possible. But it is risky and warnings for unusual colds are necessary.

The above are examples of vulnerabilities to hazards that can be seriously reduced by temporary or permanent measures leading to impact reduction. More attention is planned in the future for major diseases in the rainy season. Avoided economic losses for Ganzhou City Region were estimated to be about 120 million Yuan and identification of additional suitable land gave more than 400 million Yuan in estimated benefits.

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increases in income due to the services or information

The Longnan County Meteorological Bureau provided guidance on climate zoning for navel orange plantation in Longnan in 2002, as groundwork for preparation *of the "11th 5-Year Plan" for navel orange production in the county. The advisory together with written instructions made by the county governor was issued to all townships, villages and bodies concerned, based on which the "Longnan County Development Plan for Navel Orange production (2002–2010)" was prepared. Thanks to the planning, the citrus production has witnessed a rapid development in the Longnan County while no cultivation is found in areas of higher elevations where cold air tends to invade.*

Taking into account the climate related concerns in the process of navel orange production, the Meteorological Bureau has developed an annual meteorological service program. Apart from the "Monthly Weather Conditions" and the "Special Service Bulletin for Naval Orange Production", which are delivered on a regular basis, it also offers advices and solutions to address agrometeorological problems that might occur in different developmental stages of citrus. Relevant information is also offered via AgroEcoNet. The Longnan County Meteorological Bureau delivers weather information to the authorities concerned and farmers through SMS on a weekly basis, including tailored services for weeding and pesticide application. At a critical growth period, advisories on farming practices are offered based on weather forecasts

Another part of this case study are indeed the advisory studies related to protection from bad weather and diseases. These days, weather forecasts and such advisory services are discussed daily on cable TV, to which all farmers have access, while some also get SMS messages. At the same time, the agrometeorological information prepared by the meteorological bureaus outreaches to farmers via mobile phone short messages and TV weather forecasts, or it is delivered to individual farmers, either in written or oral form, through an intermediary entity, like a fruit industry association sponsored by farmers themselves on a voluntary basis. The following recent examples have been given:

- *January/February 2008 there was a serious cold storm, with much damage in the high lands and areas grown before planning was done, but little damage in the areas approved by planning. Binding and supporting branches was advised which gave gradual recovery*;
- *August/September 2008 there was a drought in the important period of fruit expansion. So normally irrigation will be required. However, a nearby typhoon with much rain for the area was forecasted, so an advice was given not to irrigate. Heed was taken to this message and a lot of water and efforts was saved by not irrigating as advised.*

The Xinfeng County, Jiangxi Province, the so-called "homeland of navel orange in China", has a high yield of good quality oranges, hence it has been designated "a green-food demonstration site". With climate zonation, analysis on climatically favorable zones and advisories on meteorological disaster prevention, the local meteorological bureau provides climate services forachieving the long-term vision *of navel orange production in the county through technical support. In Xinfeng, the following protection stages were distinguished in the services after the basic mapping had been applied for planning purposes*:

- *late March/early April, if anticyclones are threatening to bring more than 3 days of drought, there is sprinkling or other irrigation applied to prevent too much flower dropping*;
- *during heavy summer drought, furrow irrigation must assist in useful fruit expansion although light drought can be beneficial*;
- *too heavy rain makes drainage with furrows necessary. This is especially important during maturing phases and warnings for rains are important at this stage*

L. Difficulties encountered in introduction and use of good example of agrometeorological services or information

Due to functional limitations of the Met Bureaus, it is not common for agrometeorologists to involve themselves in agrometeorological services for citrus site selection and hazards prevention. In collaboration with authorities concerned, technical services are mainly provided to citrus growers indirectly and direct farmer oriented services are rare. Citrus growers have low awareness of weather information and services, due to their limited coverage

M. Difficulties of the service or information as seen by the farmers concerned

Some citrus growers are not fully aware of agrometeorological information for avoiding or reducing meteorological hazards, especially in selection of growing sites. As winter comes, due to such factors as large acreage, complex terrains, etc., farmers are often helpless, without any effective measures to take. The conventional measures like smoking and covering require large manpower, and are therefore only applicable to smaller orchards. The citrus is water demanding during the fruit enlarging period. These days the weather in Jiangxi province during fruit production is mainly sunny with high temperature and less rainfall. Drought may occur if irrigation fails. In general, farmers often request Meteorological Bureaus to launch rainfall enhancement operations, that cannot be met

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Major demands include accurate and timely weather forecasts. Meteorological Bureaus need to continuously improve forecast accuracy and to increase channels and frequencies of service deliveries. Advices in weather information are less operational, and agrometeorologists should consider the actual local realities in agricultural production when preparing materials

O. Chances of expanding the application of the improved example

It is necessary to carry out and facilitate zoning and climate feasibility studies in a timely manner, targeting agricultural plans of the government, to provide direct services to the authorities concerned before decisions have been made. With the "Scientific & Technical Advices", agrometeorological information is provided to the Fruit Industry Association and other agents. The agrometeorologists are in a better position to provide advices and suggestions for agricultural restructuring by participating in the relevant meetings organized by local authorities

P. Related examples found elsewhere in the Province (or in the country for that matter)

For example, climatic zoning for high-quality rice and pear conducted in Jiangxi Province, and for sugar cane production in Guangxi AR. The information required and methods used may vary, temporal and spatial resolutions of products and applicability may be different

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

The refined naval orange oriented agroclimatic zoning was based on the third agricultural climatic zonation accomplished by the China Meteorological Administration in 1998–2001. Research was done concerning a Digital Elevation Model (DEM). It contains digital geographic information that characterizes spatial location and topographical attribution, e.g. latitude and longitude, altitude and slope, in the grid format with a resolution of 25 × 25 m. A Navel Orange Land Use Data System collected Thematic Mapper satellite imagery of navel orange growing season in June–July with a resolution of 30 × 30 m. Through GPS based ground truth calibrations, navel orange land use was analyzed and classified into three categories, i.e. existing navel orange cultivable land, sparse woodland and other forest land. Climate data were collected from meteorological stations in the area under investigation and in seven surrounding areas with different altitudes. Climate factors included annual cumulative temperature (≥ 10 °C), annual mean temperature, multi-year average of extreme minimum temperature, annual sunshine hours, annual precipitation, data that are closely related to the navel orange yield and quality, covering a timeframe of 40 years (1961–2000).

A model showing correlations between climatic factors and geographical factors like latitude, longitude and altitude was established to derive climatic factors on a particular grid point. A grid map showing distribution of climatic factors was drawn using a GIS spatial analysis module before a climatic zonation was made describing the suitability for citrus plantation. On the basis of the climatic zoning map and cultivable land use categories, the GIS spatial analysis module, which was input with a judgment term, generates a climatic zoning map describing navel orange land use suitability through overlap calculations. Climate assessments were made *to calculate the total acreage suitable for citrus plantation, providing advisories for layout adjustment, cultivation sites and preparedness for meteorological disasters.*

After earlier preparative visits by Profs. Zheng Dawei (CAU) and Kees Stigter (APMP, Agromet Vision) in 2005 and 2006, and after a new visit with discussions on the above case in October 2008, we already reported on this service preliminarily in the information sheet

Stigter K, Xie Yuanyu, Liao Zhihui, Rao Qiusheng, Li Yingchun, Zheng Dawei, Wang Shili, Ma Yuping (2008) Recent identification of two agrometeorological services in Jiangxi Province, Southern China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

R. Could research assist in improvement of the service/information and how?

The previous agroclimatic zoning is based on the meteorological conditions of the targeted crops, which provide a general large scale guidance (e.g. national or provincial). This is insufficient for smaller scales (e.g. at county level). With the availability of so called 3S technologies, zoning maps at a resolution of $25 \times 25\,m$ *can be produced. Non-climatic factors such as land use categories and terrains may be taken on in climatic zoning, providing more useful guidance.*

It is necessary to enhance the studies on climate adaptation indicators for major crops, which is the basis for delivering agrometeorological services. However, the current study is clearly insufficient to meet recent demands of agricultural production and to respond to global warming. It is essential to come up with more specific and operational measures for meteorological hazards prevention and mitigation. That is why presently agrometeorological information and associated services appear to be less relevant and operational

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

Macro decision making oriented services should be associated with routine services in the whole process of citrus production. Climatic feasibility studies for citrus planting and zoning can be supportive to the overall planning by government. Agrometeorological services should demonstrate directly to the stakeholders the importance of agroclimatic zonation and encourage them to consider climatic factors and climate behavior in agricultural production before an action is taken.

Through not-governmental organizations such as a science & technology association and individual scientists, advisories can be delivered to relevant stakeholders in support to their decision making. For example, on 29 October 2002, the Climate Feasibility Study and Climate Zonation for Navel Orange Cultivation, in Gannan, prepared by local agrometeorologists and carried in the "Voice from Scientists – No. 35", was submitted to local governments, including the fruit industry bureau, the forestry bureau, etc.

Through their participation in meetings on agricultural restructuring, organized by local authorities, agrometeorologists can offer advices and suggestions from a meteorological perspective in adaptation to an initiative. For example, in November 2002, agrometeorologists took part in a meeting hosted by the Ganzhou City Agricultural Development Office to assess and review the requests from four counties (Ningdu, Ruijin, Huichang and Xingguo) to change from straw fed livestock and poultry industries and water based industries (aquatic products, water fowl and aquatic plants) to the citrus industry.

In a close partnership with the agricultural sector, agrometeorological services delivered in the process of navel orange production should firstly be oriented to the agricultural sector. The latter then develops more specific measures and policies, based on these agrometeorological advisories, for implementation by agricultural enterprises, plantation owners and farmers

[Original edited by Xiao Hongxian and collaborators (China Meteorological Administration (CMA), Beijing) from draft Chinese texts by the author mentioned under C, solicited and collected by Zheng Dawei, Ma Yuping and Wang Shili; the above version was edited by Kees Stigter, using the original, his own mission reports and another English draft translation by Xiao Hongxian and collaborators of a Chinese draft project report by the author mentioned under C and solicited and collected again as indicated above. The material given above will after further amendments be used in the near future to draw general lessons on agrometeorological services in China and to validate the present services for future improvements as wanted by CMA.]

II.C.VI *Protocol number CVI*

Short name of example:

Demonstration and extension of relay intercropping of late rice into lotus, enhanced by climate change

A. Country/province where example was found

China, Jiangxi and Henan Provinces

B. Institute providing the example (with address)

Jiangxi Provincial Research Institute of Meteorological Sciences (Jianxi Provincial Meteorological Administration), No.109, Bei'er Road, Nanchang City, Jiangxi Province

C. Researchers that collected/described this example (with the e-mail addresses)

Li Yingchun (jxnclyc2003@tom.com)

D. Field(s) of Agrometeorology to which the example belongs:

[Use the fields of interest defined for registration of members of INSAM]

Agro-Climatology (AC), Agrometeorological Services (AS), Climate Change (CC), Climate Variability (CV), EXtension (EX), Food Security (FS), Multiple Cropping (MC), PHenology (PH)

E. Natural disasters (s) and/or environmental problems to which the example is related

Chilling damage (early in White Lotus); cold winds, also inducing dew (late in Rice)

F. Way, in which the example was found, defined and collected

To make full use of climate and land resources in the idle late autumn season after lotus has been harvested, based on an analysis of the local heat conditions, agrometeorologists have proposed a technique for growing white lotus interplanted with late rice. In fields normally used for growing rice, white lotus is planted as an early crop, then interplanted with late rice as a late crop. In 1990, an experiment on white lotus interplanted with late rice was launched, through which the relevant techniques were preliminarily developed. In 2006, with a poverty alleviation fund from the China Meteorological Administration (CMA), the "White Lotus Interplanted with Late Rice Piloting and Demonstration Project" was launched to further demonstrate and promote this farming technique

G. Farming system(s) in which the agrometeorological service is applied or to whom the agrometeorological service is provided for actual use

Guangchang County, which is situated in the southeastern Jiangxi Province, has a history of 1,300 years of lotus planting. It is known as the "Land of White Lotus". A double rice crop is also grown everywhere in the area

H. Region of the country (countries), where the example can be found

Apart from the demonstration sites, mentioned under I, this practice of growing white lotus interplanted with late rice has been adopted in various townships in Guangchang County

I. Villages where the examples can be found

Baitian Village, Xujiang Township; Qianshan Village, Qianshan Township; Xifang Village, Toupi Township and others in Guangchang County

J. Describe the good example of the operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problems(s) concerned

As a traditional practice, white lotus, with a growth period of about 170 days, is normally transplanted during late March till early April. These days Ganlian-62 is planted in fine weather in early April. With an increased planting density, improved management of water and fertilizer are used to trigger an earlier and rapid growth, and to ensure early flowering, full blooming and a higher yield. Leaves are picked in a timely manner. The growth and development of flowers, buds and seeds of white lotus have a lot to do with sunlight. Its flowering stage begins in early June and ends in early or mid August. At this time, there are still 10–20% lotus seedpods left, hence the optimal period for interplanting.

When temperature, soil and fertilization are appropriate, being exposed to sufficient sunlight, healthy lotus produces robust flowers and buds in a large number. When cumulative temperature (≥ 10 °C) reaches around 1,800 °C (in late June), the plant enters into a full flowering stage. The high density in lotus fields leads to obviously insufficient sunlight. It is necessary to remove flowerless leaves 1–2 times. Afterwards, each time when lotus seedpods are collected, the old leaves on the same section ought to be removed at the same time, to expose it to more air and light for the sake of photosynthesis, and for reducing nutrient consumption.

Harvest starts from July and may continue to mid or late September. The average local air temperature is just below 20 °C in October and just below 14 °C in November. Farmland remains idle from late September and in these 2 months. In the demonstrations, the interplanting with late rice proved itself and farmers enjoyed a bumper harvest in both lotus and grain production, with greater economical benefits.

Early maturing late rice needs around 105 days (mid July to early November). Heat availability would not be enough for late rice if it would be planted after lotus seeds are harvested. In order to maximize the agroclimatic resources, intercropping should be adopted. Through an analysis of how the local temperature changes and how much heat is needed by late rice, it was found that 10–20 August would be a right period for interplanting lotus with late rice.

Late rice sowing is scheduled at the cumulative temperature (≥ 10 °C) needed for sowing and safe heading stages of both conventional rice and hybrid rice. Because of the lotus, the rice is 45 days in the nursery, 10 days longer than normal, so the rice is transplanted later than usual. This early maturing rice would then be in a flowering stage in mid or late September. This technique enables white lotus and late rice to grow together for about 1 month. Interplanted late rice accumulates about 1,300 °C more than sole paddy fields. The lotus normally fetches a high prize and the rice is an additional bonus. The lotus may lose 10% of its harvest because of the rice but under land scarcity the late rice is a useful addition.

Local daily average temperature of 20 °C ends around 8 October. So in a normal year, interplanted late rice can head fully and safely. In the 1970s, when the local climate was rather chilly, cold windy weather with dew occurred frequently in the later stages of late rice, compromising the normal growth and yield production. Since the 1990s, due to climate warming, the impact of cold air in the autumn has been much smaller. The period with a temperature of 10–20 °C adds up to about 210 days, long enough to ensure a safe heading period and a relatively higher yield of late rice. Climate warming is conducive to interplanting white lotus with late rice

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increases in income due to the services or information

Services and promotion are launched in close collaboration with local governments and agricultural technique extension bodies. Farmers, who once planted white lotus, know how to manage lotus fields. The designated demonstration acreage totaled 1,400 mu (93 ha). In terms of growth and development, the Guangchang County Meteorological Bureau distributed three handouts on how to cultivate white lotus interplanted with late rice, and gave 8 field classes. Agrometeorologists and agricultural technicians provided technical guidance and relevant information in 22 demonstration sites. Such sites have to be identified before designating a demonstration base and should be well managed to raise the interests of farmers around.

With support of the local governments, special assistance is combined with on-site guidance. At demonstration fields, targeted farmers are selected. Apart from technical guidance, funds and material support are provided. Eight candidates are families facing financial difficulties but literate, with scientific passion, and willing to be demonstration related. In March 2006, an agreement on White Lotus Interplanted with Late Rice Pilot Demonstration Project was signed between the Guangchang Meteorological Bureau and farmers from the three aforementioned *villages (see I), to clarify responsibilities and benefits of the two parties for the sake of its implementation.*

The whole process takes about 200 days. The average yield of white lotus was 55 kg mu^{-1}, with the highest being 60 kg and the lowest 52.5 kg. The average yield of the late rice was 300 kg mu^{-1}, (highest yield: 361.5 kg and the lowest yield: 225 kg). Compared with double crop rice (700 kg mu^{-1}), the additional per unit income is 830 Yuan. For the total acreage (1,400 mu) this means an additional earning of 1,162 million Yuan. Compared with single crop white lotus, the additional per unit income is 450 Yuan. The total income would be 630,000 Yuan.

The success by meteorologists with this practice in Guangchang County was recognized by the local township officials and farmers at large, who deem it a good farming practice that should be promoted widely with technical guidance covering more aspects. As climate warming foresees a higher frequency of extreme and abnormal weather events, it is necessary to take into account the low temperature risks in the late stage of this farming practice. One should stay abreast of weather and climate forecasts, in order to adjust the farming practice, or to take protective measures when necessary

L. Difficulties encountered in introduction and use of good example of agrometeorological services or information

Outreach was insufficient. Communication on this case was effective with the meteorological communities but insufficient with local authorities and communities via such mass media as TV and newspapers.

Demonstration was too short to show the advantages of lotus interplanted with rice. Due to limited resources, the demonstration lasted only 1 year, during which mid-May and early June experienced persistent low temperatures and the period of 10–13 September saw a severe cold induced dew event, both detrimental to the growth of white lotus and late rice respectively

M. Difficulties of the service or information as seen by the farmers concerned

White lotus interplanted with late rice is time sensitive. Due to lack of labor force, some rural households failed to plant the late rice timely, resulting in shorter growth periods and lower yields. During the demonstration, Meteorological Bureaus signed contracts with farmers, according to which the former subsidized seeds and fertilizers. They would also compensate any losses compared with growing sole white lotus or a double rice crop in case of failure of the interplanting. Due to limiting funds, the scope of the demonstrations was restrained

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

The practice is labor intensive and time sensitive. It requires quick harvests and adequate labor input during the interplanting period. The demonstration by

Meteorological Bureaus just showed their leading role, and farmers began to have economic benefits. However, large-scale promotion still calls for financial and technical support from governments at various levels

O. Chances of expanding the application of the improved example

To facilitate this farming technique, the following actions need to be taken: raising farmers' interests by demonstrating with successful pilot projects; special assistance to selected farmers in combination with on-site guidance to other farmers; technical training in combination with scientific outreach; agreements to be signed with the farmers

P. Related examples found elsewhere in the Province (or in the country for that matter)

Similar cases are reported, but the details are not clear

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Research has suggested to select an improved precocious and high yielding variety like Ganlian-62 or Taikonglian-3, which requires a whole growth period of 165 days or less with a stable harvest. It was also suggested to select a precocious and high-yield variety like Weiyou -64-78130 and Er'you-3027. The sowing stage of Weiyou-64 would be around 15 July. The seedling age at transplanting would be about 25 days. Cumulative temperature ($\geq 10\,^{\circ}C$) in both sowing and safe heading stages may this way exceed 2,150 °C. If Weiyou-64 is sown on 10 July, the seedling age at transplanting would be about 30 days. Cumulative temperature from sowing to safe heading stage may then be up to 2,300 °C.

After earlier preparative visits by Profs. Zheng Dawei (CAU) and Kees Stigter (APMP, Agromet Vision) in 2005 and 2006, and after a new visit with discussions on the above case in October 2008 we already reported on this service preliminarily in the information sheet

Stigter K, Xie Yuanyu, Liao Zhihui, Rao Qiusheng, Li Yingchun, Zheng Dawei, Wang Shili, Ma Yuping (2008) Recent identification of two agrometeorological services in Jiangxi Province, Southern China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

R. Could research assist in improvement of the service/information and how?

The intercropping technique has matured, but the key factors include economic benefits and farmers' interests in its adoption and these should be further investigated

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

Persistent low temperatures in May–June tend to affect budding and flowering of white lotus, leading to less flowers and more dead buds in the initial flowering stage. Preventative measures are related to regulation of temperature with water. When cold air comes, deep irrigation should be applied. When the cold air is gone, shallow irrigation is needed. Before cold air comes, heat preservation agents may be sprayed.

Cold moist windy weather in the late growth stages of late rice has a severe impact on the differentiation and heading of late rice panicles. Preventive measures are again related to regulation of temperature with water. Taking advantage of the greater thermal capacity of water, when the cold windy weather comes, deep irrigation is applied, heating agent is sprayed, foliar fertilizer is sprayed before the cold air comes, to mitigate damage by cold moist wind.

Subsequently, the agrometeorological information and services are indispensable throughout the growing seasons.

[Original edited by Xiao Hongxian and collaborators (China Meteorological Administration (CMA), Beijing) from draft Chinese texts by the author mentioned under C, solicited and collected by Zheng Dawei, Ma Yuping and Wang Shili; the above version was edited by Kees Stigter, using the original, his own mission reports and another English draft translation by Xiao Hongxian and collaborators of a Chinese draft project report by the author mentioned under C and solicited and collected again as indicated above. The material given above will after further amendments be used in the near future to draw general lessons on agrometeorological services in China and to validate the present services for future improvements as wanted by CMA.]

II.C.VII *Protocol number CVII*

Short name of example:

Water saving irrigation determined by soil moisture forecasting for wheat farms in the Huang-Huai-Huai Plane, Henan

A. Country/province where example was found

China, Henan Province

B. Institute providing the example (with address)

Henan Provincial Research Institute of Meteorological Sciences (Henan Provincial Meteorological Administration), No. 110, Jinshui Road, Zhengzhou City, Henan Province

C. Researchers that collected/described this example (with the e-mail addresses)

Yu Weidong (sqywd@sohu.com)

D. Field(s) of Agrometeorology to which the example belongs:

[Use the fields of interest defined for registration of members of INSAM]

Agro-Hydrology (AH), Agrometeorological Indicators (AI), Agrometeorological Services (AS), Climate Prediction (for Agric.) (CA), DRought (DR), Early Warning and monitoring (EW), Food Security (FS), Remote Sensing and GIS (RS)

E. Natural disasters (s) and/or environmental problems to which the example is related

Drought, Water waste in irrigation

F. Way, in which the example was found, defined and collected

Providers of the example have investigated drought occurrence, its impact mechanism and preventive measures. A soil moisture prediction model was developed for the Huanghuai Plain, on which an integrated system was set up to forecast annual soil moisture trends in the wheat/maize cycle, including a drought early warning system for the region. In recent years, through use of available monitoring data and current forecasting & warning capabilities, combined with promotion of the proven water-saving irrigation techniques the Meteorological Bureau provided drought oriented agrometeorological services to increase water use efficiency and crop production, to reduce production costs and to ensure sustainable agricultural development

G. Farming system(s) in which the agrometeorological service is applied or to whom the agrometeorological service is provided for actual use

Supplementary irrigated wheat production

H. Region of the country (countries), where the example can be found

The Huanghuai Plain (in the Yellow River & Huai River Basin) is one of China's major production areas for wheat, maize, cotton and cash crops. Water saving irrigation technology has been applied to over 1 million mu (66,000 ha) of farmlands in the selected areas in Henan, Shandong, Anhui and Jiangsu provinces of the Huanghuai Plain in 2006–2007. Such techniques as straw mulching, deep tillage, multi-purpose anti-drought sprays, irrigation indicators and calculated water amounts for irrigation were widely adopted here

I. Villages where the examples can be found

Most townships in Henan province have used this irrigation decision making system

J. Describe the good example of the operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problems(s) concerned

Making a soil moisture forecast is to analyze and predict variations in the soil water storage in a given period. Based on the concept of water equilibrium in field soil, future variations in soil moisture can be identified, considering the current soil moisture and the potential impact of future weather conditions and water consumption for crop growth. According to the initial soil moisture and its forecast in a certain time frame, as well as the water demand for crop growth at certain soil moisture conditions, assessments are made on the impact of soil moisture on agricultural production. Then an early warning of the drought severity is issued. Accordingly, irrigation options and other responsive measures are also proposed.

Appropriate physical and chemical measures are effective to improve efficiency of soil water. For example, straw mulching can change exchange properties at the surface to decrease soil evaporation and save soil moisture. Deep tillage is favorable for deeper rooting of crops, making use of soil moisture in a deeper layer and increasing drought resistance. Anti-drought sprays may increase resistance of leaf stomata and reduce evapotranspiration.

The soil moisture in Huanghuai Plain is monitored on a real time basis by using polar meteorological satellite data and ground observations. It is aimed in first instance at providing basic data for making grid point soil moisture forecasts. Secondly it aims at analyzing the drought conditions according to different soils and drought indices for crops in various growth stages, all based on satellite observations and in situ observations. This having been done, monitoring and analysis *products on soil moisture and drought patterns in Henan province are disseminated each decade, based on drought statistics and drought distribution across the region.*

Two products are available, based on the soil water equilibrium equation: (1) soil moisture forecast based on the 10-day soil moisture observations from 117 weather stations in Henan, taking into account the spread of weather forecasts and short-term climate predictions; (2) grid-point soil moisture forecasts based on satellite data from FY, NOAA and EOS, considering NWP outputs, soil categories, topographies and other supplementary land information.

For the soil moisture forecast, the evapotranspiration is calculated from the in-situ observations at local stations, and regarding the grid point forecasts, the evapotranspiration is derived from meteorological data of NWP products. Comparing soil moisture forecasts for different soils, appropriate water indicators in different crop growth stages and drought indices, the actual drought early warnings are prepared for decision making in drought prevention and mitigation.

More than 10,000 copies of agrometeorological information handouts, like "Integrated Measures against Drought" have been distributed directly to farmers. It tells farmers how to get prepared for drought faced by winter wheat in the Huanghuai area, including deep tillage, crop residue return, straw mulching, anti-drought sprays, effective irrigation indicators and water amounts for irrigation of winter wheat.

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increases in income due to the services or information

To address the needs of local governments and agencies for guiding agricultural production, the Henan Meteorological Offices are active in delivering a series of agrometeorological services, like soil moisture monitoring and forecasting, and water saving advices in terms of major crops irrigation. So far, a province wide soil moisture monitoring network has already taken shape, consisting of 117 stations that measure soil moisture in a depth of 10–50 cm on 8th, 18th and 28th of each month respectively. Out of these stations, 30 basic agrometeorological stations measure the soil moisture on 3rd, 13th and 23rd of each month additionally. This network issues a Soil Moisture Monitoring Bulletin and an Agricultural Drought Forecasts every 10 days.

Moreover, a provincial drought remote sensing system has become operational, which is based on the data from satellites. The Meteorological Bureaus at provincial, municipal and county levels also provide the local governments and relevant authorities with weekly, decadal and monthly agrometeorological bulletins and decadal Soil Moisture Monitoring Bulletins and Agricultural Drought Forecasts.

To enable farmers to better understand the preventive measures against drought, the Meteorological Bureaus disseminate the agrometeorological information through TV forecasts, telephone service (No. 12121), lectures, newspapers, internet and other mass media to the local government and farmers. The information *targeted to agricultural production managers and farmers include 1–7 days weather forecasts, early warnings for agrometeorological disasters (late frost, drought, cold injury, dry hot wind etc.), relevant advices concerning irrigation decisions, agricultural production, drought preventive measures and disaster assessments.*

The food productivity in the areas where water saving measures were taken witnessed an increase by 5–10%, while the frequency of irrigation was reduced by 1–2, saving water by 500–800 m^3 or over RMB 500 Yuan ha^{-1} annually. Through this increased efficiency of soil moisture use and water saving, farmer's income will increase to ensure food security.

The crop growth and yield production of the demonstration farmlands, where early drought warning and integrated drought preventative measures were adopted, have been significantly improved relative to those in control farmlands in terms of number of wheat ears, grain counts and grain weights. Based on 2005–2007 statistics of 8 locations (e.g. Tai'an in Shandong Province, Mengcheng in Anhui Province, Fengxian in Jiangsu Province, Qingfeg, Huojia, Xiayi, Fanqu and Qixian in Henan Province), wheat yields from demonstration farmlands increased by 6%. Among others, the wheat yields in 2005–2006, facing moderate drought, increased in a range of 2–10%, with an average increase of close to 5%. The wheat output in 2006–2007, with normal precipitation, increased by 3–12.5%, with an average increase of over 7.5%.

Crop water consumption is reduced as integrated drought combating measures are taken. According to the statistics from the demonstration sites, over the whole growth period of winter wheat they reduced the irrigation frequency by 1–2 times. Including the gain for summer maize irrigation frequency of 1, savings were about 77,400,000 m^3 water. This is a very important approach for easing the water shortage and promoting sustainable development in agriculture.

With multipurpose drought preventive measures, the soil moisture loss is curbed in different ways. Water use efficiency is improved accordingly. Soil moisture at demonstration sites was higher than that at control sites. According for example to measurements from mid-January to early June in Huojia, Henan Province, average soil moisture at 10–100 cm in demonstration sites was 44% higher than that of control sites. Average water content by weight in Tai'an, Shandong Province, in March–April was more than 8% higher than that of control sites

L. Difficulties encountered in introduction and use of good example of agrometeorological services or information

In the current decision making approaches, agrometeorological information has been delivered to governments and authorities. They disseminate it down to farming technique facilitation stations at township and village levels, which, in turn, guide local farmers on how to plant on a guided basis and how to prevent or get prepared for agricultural hazards. However, some of this information and these services are not directly and quickly accessed by farmers

M. Difficulties of the service or information as seen by the farmers concerned

Farmers are able to get informed of general weather forecasts through some media, including TV and telephone, but too many are unable to receive detailed and practical recommendations on amounts and timing of irrigation

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Farmers need timely access to agrometeorological information. A modern information and service platform and information dissemination system may be established to extend product delivery directly to the production frontlines. Efforts should be made to improve multi-channel meteorological information distribution with a focus on such bottlenecks as "last mile" access

O. Chances of expanding the application of the improved example

Drought is a common issue in North China. This agrometeorological service can be applied to that whole region

P. Related examples found elsewhere in the Province (or in the country for that matter)

Cases can be found in many provinces like Hebei, Anhui, Shandong and Jiangsu

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

For the purpose of forecasting when and how much to irrigate, station wise and grid wise, a drought index G (water deficit in %) is used over the growing season, calculated as (W−E)/E, with precipitation W (actual or forecasted) and Penman/Monteith reference evapotranspiration E (actual or forecasted up to 30 days), calculated with FAO software. Numerical weather forecasts and medium and long term weather forecasts are used.

In a long period of experiments, using crop phenology and crop conditions, a table for G has been constructed for (1) the whole growing period of wheat, but also for the three phases (2): period of sowing; (3): stem elongation to ear emergence and (4): ear filling to maturity. For light drought, G-values must remain smaller than 15 (for period 1), 40 (for period 2), 15 (for period 3) and 20 (for period 4) respectively for these four periods. For moderate drought, these G-values must be between 15 and 30 (for period 1), 40 and 50 (for period 2), 15 and 45 (for period 3) and 20 and 35 (for period 4) respectively. Severe drought is experienced when G is between 30 and 50 (for period 1), between 50 and 70 (for period 2), between 45 and 70 (for period 3) and between 35 and 45 (for period 4) respectively in these four *growth situations. Very severe drought means G-values over 50 (for period 1), over 60 (for period 2), over 70 (for period 3) and over 45 (for period 4) respectively.*

Through many improved research efforts, the dynamic soil-moisture monitoring has become operational with multiple remote sensing modalities. The Agrometeorological Model in Support to Decision making (AMSD) has been verified and improved for applications over the Huanghuai Plain. In addition, the soil moisture forecast is nested into the model for developing the decision making system for water saving irrigation. An objective function is applied to a comprehensive analysis from the perspective of achieving optimal economic benefits and water use efficiency, together with response advisories for decision making on whether or not irrigation will be applied, how much water will be used, and what specific dates will be chosen for irrigation.

After a visit with discussions in October 2008 we already reported on this service preliminarily in the information sheet:

Stigter K, Chen Huailiang, Yu Weidong, Liu Ronghua, Zheng Dawei, Wang Shili, Ma Yuping (2008) Recent identification of two agrometeorological services in Henan Province, Central China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

R. Could research assist in improvement of the service/information and how?

By using WEBGIS and 3S technologies, a WEBGIS-based decision-making system for Huanghuai Plain water saving irrigation was developed. This is operationally becoming mature by providing, through Internet, the relevant agrometeorological information in support to decision making for drought preparedness and mitigation, such as drought monitoring, soil moisture forecast and irrigation advisories targeted to the wheat and maize growing areas of the Huanghuai Plain.

A better scientific basis for timing and amounts of irrigation in the advisories would improve them. Advanced farmer-oriented agrometeorological service approaches and modalities should be explored. A feedback mechanism should be established to timely respond to feedbacks of users and to improve the ways of service delivery. Services and products should be more relevant, more practical and better science based, in order to avoid simply using raw weather forecasts as agrometeorological products

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

The actual forecasts are again a collaboration between meteorologists and agronomists.

[Original edited by Xiao Hongxian and collaborators (China Meteorological Administration (CMA), Beijing) from draft Chinese texts by the author mentioned

under C, solicited and collected by Zheng Dawei, Ma Yuping and Wang Shili; the above version was edited by Kees Stigter, using the original, his own mission reports and another English draft translation by Xiao Hongxian and collaborators of a Chinese draft project report by the author mentioned under C and solicited and collected again as indicated above. The material given above will after further amendments be used in the near future to draw general lessons on agrometeorological services in China and to validate the present services for future improvements as wanted by CMA.]

II.C.VIII *Protocol number CVIII*

Short name of example:

Forecasting peony flowering periods for various varieties and places in Luoyang city, Henan

A. Country/province where example was found

China, Henan Province

B. Institute providing the example (with address)

Luoyang Meteorological Office (Henan Provincial Meteorological Administration), No. 3 Compound, Jiandonglu, Luoyang City, Henan Province

C. Researchers that collected/described this example (with the e-mail addresses)

Yu Weidong (sqywd@sohu.com)

D. Field(s) of Agrometeorology to which the example belongs:

[Use the fields of interest defined for registration of members of INSAM]

Agro-Climatology (AC), Agrometeorological Indicators (AI), Agrometeorological Services (AS), Climate Prediction (for Agric.) (CA), Climate Change (CC), Climate Variability (CV), Data Management (DM), PHenology (PH), Weather Forecasts (for Agric.) (WF)

E. Natural disasters (s) and/or environmental problems to which the example is related

Climate variability, climate change

F. Way, in which the example was found, defined and collected

Luoyang City in Henan Province is one of the major areas for peony cultivation. The annual "Luoyang Peony Show", held from April to May, attracts a large number of visitors both from home and abroad. It has become a "shining jewel" of the local tourism. When both reputation and economic benefits of the "Peony Show" were increasing with each passing year, the acreage for peony plantation dramatically expanded. However, the peony flowering dates vary from year to year, in particular in the context of climate warming and related abnormal events over the past decade. Times of early and late blossoming differ about 20 days, but the entire flowering period will last no more than 15 days. Therefore, without controlling the peony growth stages and without flowering date forecasts, the "Peony Show" could be *embarrassed with inappropriate flowering dates. Especially a mistiming of the full blossoming period would disappoint visitors, and the socio-economic benefits of the show would be compromised. To prevent this to happen, accurate forecasts of flowering dates are essential*

G. Farming system(s) in which the agrometeorological service is applied or to whom the agrometeorological service is provided for actual use

Peony cultivation

H. Region of the country (countries), where the example can be found

All counties (townships, districts) of Luoyang City Region can make use of this information

I. Villages where the examples can be found

Most villages and townships around Luoyang City make use of the findings of this case study

J. Describe the good example of the operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problems(s) concerned

As the peony is an ornamental plant with large and colorful flowers, the Chinese used to consider it a symbol of wealth and rank. The spring in 2004 was much warmer than usual. Therefore the first day reaching the temperature threshold of peony growth (3.0 °C) came 1 month earlier than normal. Accordingly, the flowering dates came also much earlier than in other years. In addition, the air temperature in early April was increasing at high rate, leading to a much shorter flowering period than expected.

In the end, the flowering dates were somewhat extended as technicians took comprehensive measures, e.g. putting up sunshades to reduce temperature, spraying special chemicals and using stimulating flowering extending fertilizer plus watering. However, forecasts can be used to determine the specific dates for the opening ceremony of the show (see under F) and its other important events, and to plan arrangements for opening different sites. This will ensure visitors to be able to not only appreciate the flowering peonies but also to enjoy its prime time.

A plant grows best at a given temperatures. The entire growth period and each stage of growth require a certain level of cumulative temperature (CT). There are many peony varieties in Luoyang. Apart from the individual properties of these varieties, their flowering dates are closely related to the microclimate conditions of the cultivation sites. To observe the peony growth and relevant weather elements, the King City Park downtown was selected as basic measurement site. The Peony

Research Institute to the south of Luohe River as well as the National Peony Garden in the north of Mangling were selected as supplementary observation sites.

Based on the growth stages of the "Luoyang Red Peony" – a native variety – and relevant temperature data, the biological zero and effective CT above it, as required in each individual growth stage of the 10 distinguished (germination, sprouting, leafing, round budding, flat budding, belling, coloring, initial blossom, full blossom and fading) of that peony, could be identified. The base temperature increases over the season. In practice, the peony growth process can be understood, and therefore predicted, based on these effective CT indicators in different growth stages as well as real time or predicted temperatures. Effective temperatures, as accumulated degree days for each of these stages, are determined and added up in a phase by phase prediction leading to flowering time.

After 6 years of experience, flowering dates forecasts were issued for three places in the city, and continuously updated, all being based on the aforesaid indicators, climate predictions, weather forecasts, different peony varieties (early, normal and late) and microclimate conditions in individual sites of attraction. Normally, the preliminary forecasts on flowering dates are issued in early March and final forecasts are delivered by late March.

The three places are a center park of the city, that is hottest, so earliest. Early varieties may be used here. Well known parks, out of the center, are later, with middle varieties. The suburbs and mountains at the periphery of the city are latest, with later varieties also. So for tourists and buyers there is a long period to see and buy peonies flowering somewhere in Luoyang

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increases in income due to the services or information

In the first 10 days of March, the Luoyang Meteorological Bureau will submit an Internal Meteorological Advisory in which the peony flowering date forecasts are delivered for the current year to the Luoyang City Government and the Office of the Peony Show. By mid-March, the government will hold a meeting with representatives from the Meteorological Bureau, the Peony Research Institute and park managers to finalize dates for the opening ceremony and peony show events, taking into account the meteorological conditions, flowering date control techniques and layouts of peony show sites.

In the meantime, the flowering date forecasts will be outreached to the general public and peony cultivating farmers via such mass media as TV, radio, newspaper and internet. Moreover, the Luoyang Meteorological Bureau will launch a meteorological service portfolio oriented to governments and peony show organizers, delivering timely, continuously updated, and tailored weather forecasts and other meteorological services throughout the whole period of the event. Forecasts for the various varieties and places are presently not more than 1 day wrong.

The Luoyang Peony Show has become a comprehensive local event of tourist attractions, associated with economic or business activities instead of simply *enjoying flowers and lantern shows. Since the 1st up to the 25th Peony Show, the number of business contracts had accumulatively reached more than 1,000, with the total investment amounting to RMB 140 billion Yuan, out of which 109 billion Yuan were from overseas. At the 26th Peony Show in 2008, the number of contracts was 284 with a total investment reaching 61 billion Yuan, an increase by almost 54% compared with the previous year. The economic and social benefits from the accurate flowering date forecasts in recent years were therefore significant. Peony growing farmers have also substantially benefited from sales of flowers and Chinese traditional herbs*

L. Difficulties encountered in introduction and use of good example of agrometeorological services or information

At present, forecasting service products for peony flowering are directly made available to the Luoyang City Government and the City Office for Flowers. The said products will be delivered to the civil communities through governmental channels. Some of agrometeorological services still can not be made available to flower growers directly

M. Difficulties of the service or information as seen by the farmers concerned

Farmers can receive weather forecasts only through television, telephone and other means, but can not get access to detailed florescence forecasts in advance

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Farmers need timely access to agrometeorological information. A modern information and service platform and information dissemination system may be established to extend product delivery directly to the production frontlines. Efforts should be made to improve multi-channel meteorological information distribution with a focus on such bottlenecks as "last mile" access

O. Chances of expanding the application of the improved example

This example can be applied to the whole of Luoyang City Region

P. Related examples found elsewhere in the Province (or in the country for that matter)

Such examples do not exist

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

Observations show that sunshine and precipitation in springtime in Luoyang City and its surroundings are more than sufficient to meet the growth from germination to flowering stages. The major factor affecting the flowering dates of peonies is the heat condition. Theoretically, a plant requires given CTs to grow to a certain stage. As an indicator, a forecast of plant growth may be based on CTs. From the prospective CT required for different stages in peony growth, the effective CT was identified based on the CT above a biological threshold for each individual growth stage of peony, instead of the air temperatures above 0°C. This means that the ineffective CT (≥ 0°C) components are removed and replaced by CTs based on the biological thresholds.

After a visit with discussions in October 2008 we already reported on this service preliminarily in the information sheet:

Stigter K, Chen Huailiang, Yu Weidong, Liu Ronghua, Zheng Dawei, Wang Shili, Ma Yuping (2008) Recent identification of two agrometeorological services in Henan Province, Central China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

R. Could research assist in improvement of the service/information and how?

The forecasts with the methodology described under J appear more accurate and they are more robust than the estimates made by the Peony Research Institute through phenological calculations using the number of days in individual growth stages combined with the air temperature. Given the present accuracies, no new research appears necessary

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

The actual forecasts are again a collaboration between meteorologists and agronomists. The discussions on the forecast are more intense when the climate gives more problems than normal. In the open, flowering could be influenced by heating the soil for earlier flowering or using shade/ice/chemicals to delay flowering in the order of 10 days

[Original edited by Xiao Hongxian and collaborators (China Meteorological Administration (CMA), Beijing) from draft Chinese texts by the author mentioned under C, solicited and collected by Zheng Dawei, Ma Yuping and Wang Shili; the above version was edited by Kees Stigter, using the original, his own mission reports and another English draft translation by Xiao Hongxian and collaborators of a Chinese draft project report by the author mentioned under C andsolicited and collected

again as indicated above. The material given above will after further amendments be used in the near future to draw general lessons on agrometeorological services in China and to validate the present services for future improvements as wanted by CMA.]

II.C.IX <u>*Protocol number CIX*</u>

Short name of the example:

Winter straw mulching increasing water use efficiency and yields in winter wheat

A. Country/Province where the example was found

China, Hebei and Henan Provinces

B. Institute providing the example (with address)

Hebei Institute of Meteorological Sciences, Hebei Provincial Meteorological Administration, No. 178, Tiyunandajie, Shijiazhuang City, Hebei Province

C. Researcher(s) that collected/described this example (with their e-mail addresses)

Li Chunqiang (chunql@sohu.com)

D. Field(s) of Agrometeorology to which this example belongs

[Use the fields of interest defined for registration of members of INSAM]

DRought (DR), Agrometeorological Services (AS), Crop Protection (CP), EXtension (EX)

E. Natural disaster(s) and/or environmental problems to which the example is related

Agricultural drought, Water resources shortage

F. Way, in which the example was found, defined and collected

Already reported in 2006 to INSAM contest (INSAM protocol 16 in this book)

G. Farming system(s) in which the agrometeorological service is applied or to which the agrometeorological information is provided for actual use

North China is the major grain-producing area in northern China, where winter wheat and summer maize are planted in most parts of the region, with a cropping system of two crops per year or three crops every 2 years

H. Regions of the county (or counties) where the example can be found

After continued promoting efforts in 2003–2005, more than 1 million mu (about 67,000 ha) of farmlands in Hebei and Henan provinces adopted this technique

I. Villages where the example can be found

Very many now, even more than earlier reported in INSAM protocol 16

J. Description of the good example of operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problem(s) concerned

Annual mean precipitation in most parts of North China is 500–600 mm, mainly concentrated in the hot summer. Because of uneven spatial and temporal distribution of precipitation, with a great variability, natural precipitation cannot meet crop demands. Due to impacts of climate change, especially since the 1990s, temperature has significantly increased. Precipitation has noticeably decreased and drought is frequent. At the same time, with rapid economic development, water resources in North China have increasingly come under stress. In some areas, due to over-exploitation of underground water, underground funnels exist. Therefore, aiming at rational use of water resources, effective measures for drought prevention and resistance, sustainable development of agricultural production and ecological environment recovery becomes imperative. In recent years, as an ancient practice for preserving water content and soil moisture, the straw mulching has been more widely used.

When farmland is covered by straw, a physical barrier for exchange processes is placed on the surface of the soil, which changes the roughness of the soil/atmosphere boundary layer, as well as the dynamical thermal and moisture properties of the surface layer. Straw mulching forms a layer that interrupts the water and heat exchanges between the atmosphere and the original soil surface. So there is a warming effect in wheat fields mulched with straw in winter. Compared to bare soil, the turbulent exchange coefficient is increased, so is the mulch surface temperature, so the sensible heat flux; however, latent heat flux, that is evaporation, is decreased by the barrier to a large extent. Soil heat flux is significantly reduced due to the insulation properties of the mulch. In other words, with straw mulching, the variation of soil temperature becomes relatively stable, which prevents the winter wheat from freezing. In spring, straw mulching tends to lower the soil temperature, slowing down the rising pace of temperature. This tends to prolong the spiking stage of winter wheat and to produce larger ears on condition that supply of both water and fertilizer are sufficient.

Straw is the best mulching material and the appropriate amount is 4,500–6,000 kg ha^{-1}. Before mulching, straw should be chopped up to prevent it from pressing the seedlings. The most effective mulching period for winter wheat is from the beginning of winter, which is normally in the second or last decade of December for wheat growing areas in central and southern Hebei Province. Any earlier mulching may lead to weak seedlings, while delayed mulching may shorten the effective period and its benefits will be compromised. Straw mulching has dif-

ferent effects on soil moisture at different depths in different times. Compared to uncovered fields, larger differences in soil moisture content occur at the depth above 60 cm. Straw mulching can evidently improve the moisture contents of the soil surface layer. If straw mulching is made from the beginning of winter to the wheat jointing stage, the soil moisture of mulched fields will well increase compared to uncovered fields. The soil water content within a 1 m soil layer in straw mulched wheat fields is in the order of 10 mm higher at the jointing stage of winter wheat than in uncovered fields. Yield increases of generally between 6 and 15% have been measured and water use efficiency increases of more than 20%, but the latter are generally between 12 and 16% on a multi-year basis.

The ecological effects of the practice on farmland include two aspects – water and fertilizer. From the perspective of water, as we have seen, the effects are to reduce soil evaporation, hence preserving its soil moisture, and to improve water use efficiency. In terms of fertilization, straw residues fertilize the soil after long-term physical effects and chemical decomposition, which is a long accumulative process and becomes tangible in the farmlands with multi-year straw mulching

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increase in income due to the services or information

Straw mulching technique creates substantial benefits in terms of increasing drought resistance and production. Generally, one irrigation can be avoided, saving 20–30 m^3 water per mu and hence reducing costs (for electricity) about 20 Yuan per the same unit. Promoting the use of the straw mulching technique in Hebei and Henan provinces alone has achieved good social, economic and ecological benefits. These include reducing irrigation, lowering production costs, saving agricultural use of water, easing the shortage of water resources, creating sound micro-climatic and ecological environments for the growth of winter wheat, strengthening the resilience of crops, increasing yields but particularly water use efficiencies

L. Difficulties encountered in introduction and use of this good example of agrometeorological services or information

No difficulties have been reported, but much remains to be done. The training on mulching techniques should be oriented to agricultural technicians and farmers in the targeted areas for promoting wider use. Technical researchers and facilitators should go to the villages and hold training seminars, explaining basic principles and technical points, the best mulching time, amounts of straw to be used, etc.

Technical material easy for farmers to read and understand about straw mulching for winter wheat should be prepared. During the growing stage of winter wheat before winter comes, technical facilitators should go to the fields to disseminate dedicated service leaflets to farmers telling them about drought prevention techniques for winter wheat

M. Difficulties of the service or information as seen by the farmers concerned

No validation with farmers has been performed

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

Again, much remains to be done. Various technical services and their outreach should be conducted through all mass media and communication links. For example, via newspapers and television programs, necessary information can be made available to farmers during major farming seasons and the World Meteorological Day. Using operational agrometeorological services information (e.g. decadal bulletins, radio broadcasts), among others real-time weather and soil moisture information, decisions on drought prevention and reduction, techniques and measures for production management may be produced and issued to guide agricultural production

O. Chances of expanding the application of the improved example

Depending on where winter wheat is grown in northern China

P. Related examples found elsewhere in the Province (or in the country for that matter)

Not applicable. It should be mentioned that INSAM protocol 16 reports on an earlier phase of this example

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

A large number of experiments has shown that straw mulching can improve moisture, fertilizer, air and heat conditions in the soil, thus reducing various ecological problems related to drought and effects such as environmental pollution due to residue burning. The practice was shown to be effective for winter wheat, maize and other crops. Agrometeorologists in Hebei and Henan provinces have done some research on agro-meteorological mechanisms of winter wheat straw mulching in an effort to promote a wider use of the technique.

According to field experiments, in springtime, the soil temperature at surface level under the mulch at 14:00 h is about 9 °C lower than that of bare fields. At 8:00 and 18:00 h, it is about 3 °C lower. However, this difference decreases as a function of soil depth. On average, every 20 cm the soil temperature decreases by 0.1–0.7 °C.

Recent research also showed that the effect of straw mulching on soil moisture is related to crop growth stages. According to observations of evapotranspiration variations of wheat fields over time, it was found that during early stages (from the whole winter to the jointing stage of winter wheat), straw mulching reduces soil *evaporation and increases soil moisture. After the jointing stage, field crop evapotranspiration is the major factor.*

In the years 2004–2008, Profs. Zheng Dawei (China Agricultural University) and Kees Stigter (APMP, Agromet Vision) studied the system while visiting it and discussing it with Dr. Li Chunqiang. We reported on this preliminarily in:

Stigter K, Li Chunqiang, Zheng Dawei, Wang Shili, Ma Yuping (2008). Further identification of two agrometeorological services in Hebei Province, China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

We also could make use of:

Li Chunqiang, Li Baoguo, Hong Keqin (2008) Analysis of the temporal-spatial variation for reference crop evapotranspiration in Hebei Province. Paper presented at the International Conference on Biometeorology, Tokyo (Clim Variat-O06)

R. Could research assist in improvement of the service/information and how?

With straw mulching, conditions of soil moisture, nutrients, heat and microclimate change. Their synergic effects under the external conditions applied (irrigation, fertilization) are not yet fully understood. Therefore, the changes of soil fertility and microclimate after straw mulching need to be further investigated quantitatively

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

Although the soil evaporation is reduced through straw mulching, the field evapotranspiration as a whole is similar. This indicates that straw mulching does not change significantly the water consumption of wheat fields but only the structure of water consumption. Mulching appears to transfer water consumption of wheat fields partly from a physical process from the soil surface to a biophysical process from the plant surface. This way it partly changes from ineffective to effective water consumption, consequently increasing water use efficiency

[Original edited by Xiao Hongxian and collaborators (China Meteorological Administration (CMA), Beijing) from draft Chinese texts by the author mentioned under C, solicited and collected by Zheng Dawei, Ma Yuping and Wang Shili; the above version was edited by Kees Stigter, using the original, his own mission reports and another English draft translation by Xiao Hongxian and collaborators of a Chinese draft project report by the author mentioned under C and solicited and collected again as indicated above. The material given above will after further amendments be used in the near future to draw general lessons on agrometeorological services in China and to validate the present services for future improvements as wanted by CMA.]

II.C.X <u>Protocol number CX</u>

Short name of example:

Early warning of low temperatures and less sunshine for plastic greenhouse crops in winter

A. Country/province where example was found

China, Hebei Province

B. Institute providing the example (with address)

Hebei Institute of Meteorological Sciences, Hebei Provincial Meteorological Administration, No. 178, Tiyunandajie, Shijiazhuang City, Hebei

C. Researchers that collected/described this example (with the e-mail addresses)

Li Chunqiang (chunql@sohu.com)

D. Field(s) of Agrometeorology to which the example belongs:

[Use the fields of interest defined for registration of members of INSAM]

Agro-Climatology (AC), Agrometeorological Indicators (AI), Agrometeorological Services (AS), Climate Under cover (CU), Crop Protection (CP), Early Warning and Monitoring (EW), Natural Disasters (ND), RIsks in weather and climate (RI), Weather Forecasting (for Agric.) (WF)

E. Natural disasters (s) and/or environmental problems to which the example is related

Low winter temperatures, Insufficient winter sunshine, Frost/snow/ice/cold/wind periods

F. Way, in which the example was found, defined and collected

Plastic greenhouses have changed farming practices in northern China. They also tend to make full use of labor resources in rural areas, which is in line with China's conditions since farmers have greater economic returns with lower investments. No services for greenhouses did exist. The low temperature and sunshine conditions that limit production as well as more serious dangers needed an early warning system benefiting the vegetable growers using simple greenhouses

G. Farming system(s) in which the agrometeorological service is applied or to whom the agrometeorological service is provided for actual use

Vegetable growing under cover with low outside temperatures

H. Region of the country (countries), where the example can be found

Wherever there are plastic greenhouses in northern China

I. Villages where the examples can be found

Gaoyi, Xushui and other places in Hebei

J. Describe the good example of the operational agrometeorological services (maximum of one page A-4), with emphasis on agrometeorological components of the problems(s) concerned

Compared with a fully climate-controlled greenhouse, light, temperature, humidity and other meteorological elements in the simple plastic greenhouses are largely subject to outside weather conditions, and the man made interventions are limited. Therefore, such greenhouses are characterized by weaker sunshine exposure, high humidity and poor ventilation. The indoor vegetables, in particular fruit vegetables have a relatively high demand for light and heat. If low temperature & insufficient sunshine (LTIS) persist for a longer period, the temperature in the greenhouse will drop too much, while the humidity is likely to increase too much, which will not meet the necessary environmental conditions required for vegetable growth.

Plastic greenhouses are designed to make full use of limited light resources in northern China in both autumn and winter for producing the greenhouse effect needed for vegetable production. The microclimate within a greenhouse can be adjusted or controlled manually, as necessary, through covering by straw/mats and other simple heat conservation measures, to reduce the impact of adverse weather conditions. According to China's temperature distribution pattern in winter, the greenhouses are mainly built over the region from 32 to 43° North. The main factors affecting vegetable growth in these greenhouses are longer periods of LTIS, easterly winds, heavy snow, etc. However, based on sunshine duration and other weather conditions (fine, overcast, foggy, etc.) in the previous period and their forecasting, it is possible to monitor, forecast and warn of LTIS events affecting the sunlight greenhouse production. The "Early Warning System of Meteorological Disasters to Facilitate Agriculture" on impact of LTIS events on greenhouses is presently mainly provided by the Provincial Meteorological Bureau.

The key for forecasting and warning of such LTIS events is to identify indicators for the potential adverse weather events. The LTIS indicators vary from one vegetable to another and in different growth stages. Cucumber and tomato, which are very sensitive to light and temperature, are the most common vegetables grown in the greenhouses in Hebei Province in winter. These two vegetables are chosen to represent fruit vegetables. Although leaf vegetables have different demands for meteorological conditions, they tend to grow slowly or even stop growing or they are plagued by diseases under a prolonged LTIS, hence in depth subdivisions are *excluded. The daily sunshine duration in the open (i.e. outside greenhouses) is used as early warning adverse event indicator. The severity of the event is defined in percentage of the yield reduction, i.e. 10–30% (slight yield reduction), or 31–70% (moderate yield reduction), or 71–100% (severe yield reduction). Early warning indicators for LTIS events in sunlight greenhouses could be identified through experimental observations.*

For both cucumber and tomato seedlings, as fruit vegetables, if LTIS daily sunshine duration (DSD) (≤3 h) lasts for 2 consecutive days (CDs) or shorter, there will be no impact. If LTIS DSD continues for 3–6 CDs, it will be a slight impact. If it persists for 7–10 CDs, it will be a moderate impact. If it sustains for ≥11 CDs, it will be a severe impact. For both these fruit vegetables in transplanting stage as well as for leaf vegetables, if LTIS DSD (≤3 h) continues for 6 CDs or shorter, there will be no impact. If it lasts for 7–10 CDs, there will be a slight impact. If it sustains for 11–15 CDs, there will be a moderate impact. If it exceeds 15 CDs, there will be a severe impact. For cucumber at flowering and fruiting stages, if LTIS DSD (≤3 h) lasts for 2 CDs or shorter, there will be no impact. If it persists for 3–6 CDs, there will be a slight impact. If it continues for 7–10 CDs, there will be a moderate impact. If it is beyond 11 CDs, there will be a severe impact. For tomato at these later stages, if LTIS DSD (≤3 h) sustains for 4 CDs or shorter, there will be no impact. If it persists for 5–9 CDs, there will be a slight impact. If it lasts for 10–14 CDs, there will be a moderate impact. If ≥ 15 CDs, there will be a severe impact.

With this system, weather changes, in the form of weather forecasts, can be made available at any moment in its operational run. It focuses on the occurrence of fogy/overcast weather and its duration, essential for preparing an early warning service product in a timely manner

K. Success and advantages of the example as judged by farmers concerned, where possible also expressed as estimated increases in income due to the services or information

The service delivery channels include meteorological websites and TV weather forecast programs for the public and telephone for farmers. Relevant warning information and service products about an adverse event are disseminated in a timely manner to the agricultural management bodies and for agricultural websites, then the agricultural authorities re-disseminate the information via internet, SMS etc., guiding farmers to prevent and mitigate the impacts of the event. An early warning consists of 2 components: (1) impact analysis of past meteorological conditions, and (2) weather forecasts and warnings including preventive advices.

During the farming season in autumn, winter and spring each year, the service material for greenhouses will be prepared based on the monitoring, forecasting and warning information of an LTIS event, and it will be delivered to the Division for Agriculture and the Central Station for Agricultural Technology Facilitation under the Agency of Agriculture, Hebei Province. Relevant stakeholders find that the LTIS information for greenhouse production is released in a timely manner, that the *advisories are relevant for agricultural decision making, and that social benefits are significant.*

The Hebei Agricultural Meteorological Center has provided multiple early warning services based on weather forecasts and real-time weather conditions over recent years, covering 3 million mu (200,000 ha). These products are used by agricultural production and managerial authorities, and are widely disseminated via television, newspapers and internet, with estimated economic benefits exceeding 12 million Yuan.

Under conditions of low sunshine and at night, the plastic is covered with matting or bound straw to prevent too high reductions of temperatures in the greenhouses. So manipulation of cover over the plastic is an intrinsic part of regulating the greenhouse climate. In late December 2007, the Hebei Province met continuous overcast/foggy weather. According to the weather forecast and systematic analysis, the Hebei Provincial Meteorological Bureau produced a timely early warning for greenhouse farming, which was immediately notified to farmers by telephone. According to a survey conducted after the event, in response to the warning, farmers had prolonged the coverage time with straw, cleaned greenhouse film, unveiled the shelters around noontime to allow scattered light in, etc. With these measures, potential vegetable yield loss was reduced by an estimated 50%

L. Difficulties encountered in introduction and use of good example of agrometeorological services or information

There is almost no difficulty in promotion and application of this technique, which mainly depends on the availability of daily sunshine data and future weather forecasts

M. Difficulties of the service or information as seen by the farmers concerned

There is no difficulty for farmers. The main target is to reduce losses caused by both excessive greenhouse humidity and crop disease outbreak, that arise from low temperature and poor sunshine, as well to take preventive measures

N. Improvements envisaged or wanted/proposed in the service or information by the farmers, and the feasibility of such improvements

The future should bring the following improvements: monitoring and analyzing the meteorological environment inside the greenhouses; studying the relationship between microclimate inside the greenhouses and the meteorological environment outside in the open; predicting environmental changes in the greenhouses using weather forecasts. It is feasible to install instruments to observe microclimate in a greenhouse, and to make comparative observations and analyses

O. Chances of expanding the application of the improved example

This greenhouse oriented agrometeorological service has also been applied to some other provinces in northern China. It has for example been used in Tianjing and other municipalities, which has been widely recognized by farmers, having achieved significant social and economic benefits.

Indicators of both low temperature and insufficient sunshine in local greenhouse agriculture regions will be collected through system software to be upgraded, which could be extended to cover a much larger area through technical transfer and improvement

P. Related examples found elsewhere in the Province (or in the country for that matter)

Not available

Q. Do any research results exist on this service/information or on the agrometeorology from which it was derived?

After earlier preparative visits by Profs. Zheng Dawei (CAU) and Kees Stigter (APMP, Agromet Vision) in 2005–2007 to Hebei Province, and after a new visit with discussions on the above case in October 2008, we already reported on this service preliminarily in the information sheet:

Stigter K, Li Chunqiang, Zheng Dawei, Wang Shili, Ma Yuping (2008) Further identification of two agrometeorological services in Hebei Province, China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

R. Could research assist in improvement of the service/information and how?

Research can improve current work, e.g. further improvement of monitoring and early warning indicators, as well as the effectiveness of monitoring and early warning. It is advisable to further study how the microclimate within greenhouses changes with weather conditions outside greenhouses; to use models for making quantitative analyses of temporal and spatial variations of temperature and humidity inside greenhouses, as well as to study the quantitative relationship between greenhouse humidity and crop diseases

S. Any other comments from the collectors of this example that can help in understanding the many aspects of such services/provision of information

An only sunlight heated greenhouse is a simple farming structure for agricultural production, which mainly depends on solar radiation for heating. With the greenhouse effect, well-made greenhouses can be used to grow a variety of thermophilic *vegetables and fruits, among others, in late autumn and winter, lengthening the agricultural production season in northern China and addressing the availability of off-season vegetables*.

However, once these greenhouses meet a longer period of overcast/fog, insufficient sunshine, or when accompanied with heavy snow, strong wind and cold waves in some extreme years, it is hard to keep the greenhouse indoor temperature warm enough. This leads to cold and freezing injuries and pertinent diseases. Even when the early warning is released well in advance, it remains hard to avoid economic losses

[Original edited by Xiao Hongxian and collaborators (China Meteorological Administration (CMA), Beijing) from draft Chinese texts by the author mentioned under C, solicited and collected by Zheng Dawei, Ma Yuping and Wang Shili; the above version was edited by Kees Stigter, using the original, his own mission reports and another English draft translation by Xiao Hongxian and collaborators of a Chinese draft project report by the author mentioned under C and solicited and collected again as indicated above. The material given above will after further amendments be used in the near future to draw general lessons on agrometeorological services in China and to validate the present services for future improvements as wanted by CMA.]

II.D Communication Approaches in Applied Agrometeorology

R. Gommes, M. Acunzo, S. Baas, M. Bernardi, S. Jost, E. Mukhala, and S. Ramasamy

II.D.1 Introduction

Farm-level management decisions are mostly determined by the knowledge of the interactions between the environment, the characteristics of crops and animals, technology, socio-economic factors and the institutional context (including agricultural education, government rules, customs, etc.). Among these factors, weather remains the largest source of variability of farm outputs, directly and indirectly. It can be estimated that 20–80% of the inter-annual variability of yields stems from the variability of weather (depending on the level of development), while losses due to pests, diseases and weeds are normally around 15% (Oerke et al. 1994). Post-harvest losses are also of the same order of magnitude.

Next to "background weather variability", extreme agrometeorological events are factors that can provoke massive destruction of infrastructure, crops, livestock, fishing gear, etc. and the loss of human life (Gommes 1999, 2003). The current interest in climate change has increased public awareness of the need to reduce impacts of climate variability (in the short run) and climate change (in the long run), at a time where new sources of data and modern communications make available the tools to improve "agrometeorological communication" (Jarvis et al. 2002).

II.D.2 What Is Communication?

Communication implies a two-way process with exchange of ideas, information and knowledge. There are several components of communication such as the generation of information, its dissemination (in the sense of a one way information flow) from producer to user, information management and information sharing (in the sense of double or multiple ways of information flow), as well as knowledge generation (two way communication flow required) and knowledge management. It is stressed that communication, including agrometeorological communication, does not necessarily

R. Gommes (✉)
Environment, Climate Change, and Bioenergy Division, FAO, Rome, Italy
e-mail: rene.gommes@fao.org

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_5,

flow from one level to another, and that it takes place also inside a community, for instance among farmers or inside the agronomic research community (e.g. Stigter et al. 2007; Roncoli et al. 2009). See also Chap. IV.5. Finally, the flow of information, like heat, electricity or money, is driven by gradients. This is to say that it can be driven by supply, demand or, ideally, by both. This also means that communication at the same "level" may be more difficult than between levels, but significant innovations with a decisive advantage can eventually spread fast "by contagion" from neighbour to neighbour. Needless to say, it can be the role of communication to facilitate the contagion of innovations and to bridge technical disciplines and other soft and hard barriers.

"Communication" can also be described according to the technical means used to communicate something. For instance, conflict management communication uses specific methods and media. In this case, video has been used successfully to allow each party to explain their interests and then allow the other side to view the recording; it is a form of structured listening. Another way for classifying communication is according to the themes or areas for its applications such as environmental communication, health communication, and agrometeorological communication. The present chapter focuses on communication with and between farmers, which themselves constitute a major channel of transmission of agrometeorological information (e.g. Stigter et al. 2007; Gakuru et al. 2008; Roncoli et al. 2009). See again also Chap. IV.5.

According to Blench and Marriage (1998) (see also Mukhala 2000), studies of the impact of climate forecasts in southern Africa suggest that there is a considerable gap between information needed by farmers and that provided by Meteorological Services. There are communication barriers since the two parties have been interacting for a long time, but apparently have not been communicating effectively. Farmers know what they want (demand) and the Meteorological Services believe they know what they need to provide to farmers (offer). The communication has failed because there are no, or few shared meanings. The effectiveness of meteorological communication is determined, amongst other things, by the extent to which all persons involved in the communication transaction are competent in communicating and interpreting meteorological messages. A failure of communication means that there may be 'noise' in the communication transaction. The concept of noise refers to any factors which disturb the communication and interpretation of messages, e.g. messages being viewed as targeted for wealthy farmers and hence the emerging farmers do not pay attention.

II.D.3 Communication Targets, Messages and Meta-Messages

II.D.3.a Different Categories of Audiences

Agrometeorological communication can address several targets or "audiences", keeping in mind that, due to the bi-directional nature of communication, the concept of target is not always meaningful, nor is the target always the end-user of the message being communicated. A good example is the financial mechanisms that have been developed in the ambit of the Multilateral Environmental Agreements (MEA) such as the UN Framework Convention on Climate Change (UNFCCC). The primary message (meta-message: "remove carbon from the atmosphere") is relevant to governments as, for instance, a government may earn credits for carbon sequestration in biomass (see also Box III.4.11 in Sect. III.4.2.(ii) and Sect. III.4.5.(ε)), or, hopefully, in the post-Kyoto regime, soil carbon storage as well.

Soil carbon storage has a number of immediate benefits for smallholders, including increased soil fertility, and higher soil water holding capacity, which both result in improved food security through less variable production. If the primary message has to be implemented at the national level, it must first be converted into agricultural policies that provide incentives to reduce forest degradation or favour soil carbon sequestration (e.g. conservation agriculture). The advantages of the local measures at the individual level have then to be explained by efficient extension services: the message to smallholders is not "store soil carbon" but "achieve more abundant, more regular and more sustainable food production".

The audiences of agrometeorological communication can arbitrarily be subdivided into the categories listed below. To some extent, they are all "decision makers", even if some are active in marketing, others in politics and, others still in farming:

1. Producers, people who are engaged in the actual production of crops, livestock, forestry and inland fisheries products. This includes actually a very large array of people, including subsistence farmers and industrial farmers, mushroom growers, bee keepers and those who collect wild honey, traditional Asian shrimp growers in brackish water, women growing vegetables in cities for sale at the local market, the owners of large industrial fishing boats on lakes, etc. The least sophisticated customers, from a technological point of view, are also those more difficult to reach, particularly for real-time applications: poor farmers not having access to "modern" channels of communication, or modern types of information, such as seasonal forecasts (Meza et al. 2008). See also Chaps. IV.2 and IV.5.
2. Extension (see also Chap. IV.5), often called "outreach", includes the people and the techniques responsible to ensuring the circulation and efficient use of the messages. According to IAC (2004) three models of agricultural extension have dominated extension debates in Africa since independence. First the quantitative model, which was introduced in the 1960s by experts who assumed that new technology could be transferred by massively expanding agricultural extension services. The systems collapsed mainly because of high costs. The second model – the Training and Visit (T&V) extension model – put a lot of emphasis on improving the management of national extension systems, but turned out to be expensive and ineffective. A third extension privatization model is being tested based on the positive experience of private extension and many village and church groups in Africa who set up their own extension networks after the collapse of T&V programs.

3. Experts (see also Chap. IV.4) are not a "usual" category. At the more traditional/subsistence end of the spectrum, producers, decision makers and "experts" actually overlap. At the more technical end, there is a specialised category of people who design farm buildings and stables and air conditioned tractors, scientists who develop crop yield-weather models, those who breed new varieties of broilers, biotechnologists, crop insurance experts, those responsible for warning and advisory services, specialists writing up agricultural policies, etc.
4. "Commercial" categories involved in marketing and trade, the manufacturing and trade of farm tools and inputs (fertiliser, pesticides, machinery, infrastructure), manufacturers of livestock and poultry vaccines. See also Chap. IV.3.
5. Policy decision makers at international, national, regional, local levels ((inter)national institutions, ministries, administrations, municipalities). See also Chap. IV.2.

Diverse communication tools are needed for these different categories: producers need very concrete recommendations for planting, crop and natural resources management, harvesting; extension people need guidelines, tools; decision makers need short documents with highlights and precise recommendations for action; technical experts need analytical documents on data and methodologies.

II.D.3.b Differences Between Audiences

To communicate effectively taking into account the various audiences listed above, agrometeorologists need to recognize the characteristics and needs of the target audience. This helps them to encode information in ways that will be easy for farmers or other users to decode. Agrometeorological Services, who are often the original source of agrometeorological advice should ask questions like: What are the characteristics of the target audience? What type of farming systems do they operate? Which information do they need? What are their levels of education or literacy? What language would they be comfortable using? What is their socio-economic status? What is their gender? What media or channel can be appropriate to transmit information? Unless such questions are taken into account, communication (sharing of meaning) may not take place.

Language is a basic tool of communication through which simple or complex ideas are conveyed. An effective communicator should be sensitive to the nature of his or her language (Whitman and Boase 1983). When writing for the public, Yopp and McAdams (1999) stress that technical terms or jargon should be avoided as much as possible. The use of technical terms creates a perception that the information is for "insiders" only, those who are familiar with the jargon. "Outsiders" or non-experts who could benefit from the information can be estranged both from the source and the message. If jargon is used for farmers with low education levels, technical terms may create a feeling that the information is reserved for elite farmers. As a result, poorly educated farmers may feel excluded or perceive the information as exclusive.

Providers of meteorological information, including agrometeorological information, should understand that words do not have the same meaning to all people. To assume that they do, is to ignore a fundamental principle of language – Words do not have meaning, only people do. Meteorological Services (NMHSs) or meteorologists know what they want to convey in a seasonal climate forecast, but farmers may perceive the information differently. A failure in communication can occur even when using everyday language. If misunderstanding can take place so easily in everyday language, imagine the problem with scientific or technical language. Information only has value when it is disseminated in such a way that the end-users get the maximum benefit in applying its contents (Weiss et al. 2000). This statement is even more valid for agrometeorological information.

The inventory elaborated by FARA-Africa (Gakuru et al. 2008) shows that the provision of weather forecasts on a daily basis is just information. Generic data are made available by a provider and are sent to the rural community through various media such as radio, television, newspaper, rural telecentres, and mobile phone alerts. However, the rural community does not get involved in the generation, validation, evaluation, understanding and appreciation of this information. This "take it or leave it approach" puts the rural community as a passive observer. The horizontal transfer of knowledge should be a more integrated learning process, where learning by doing, learning through participatory research, evaluation and knowledge management, CD and internet based learning, face-to-face interactions, etc. are the basis of the capacity building process (Roncoli et al. 2009).

A study, prepared by the Stockholm Environment Institute and commissioned by the Rockefeller Foundation, wanted to identify and understand the extent to which, and ways in which, information from climate change models is being integrated into agricultural development practice and decision making in Africa (Ziervogel et al. 2008). One of the recommendations refers to the need of "translators" who understand the challenges on meteorological information providers and farmers and can act as information channelling (Throughout this book these "translators" have been called "intermediaries", as defined and exemplified in Part I and also dealt with in Chap. IV.5). The challenge with this task is that it requires skills that many of the people currently engaged in climate change adaptation simply have not developed. Specifically it requires the ability to translate science concepts into those that users understand and can use, without distorting the concepts. It also requires in-depth understanding of users' needs and the potential opportunities for using climate change projection data (See again also Chap. IV.5.)

II.D.4 Communication and Agrometeorology

II.D.4.a Sectors Affected by Weather

We take agrometeorology in the broadest sense, i.e. the "science" of the interactions between weather and climate and agriculture, where agriculture too is taken in the broadest sense, i.e. fisheries, forestry, crops and animals from production or collection to consumption, i.e. including the items in Fig. II.1. All the steps illustrated in Fig. II.1 are weather-dependent and, therefore, are likely to benefit from agrometeorological knowledge (science) and advice. The figure covers both quantitative and qualitative aspects. In the area of food, we could mention food production (amounts), food security (amounts and regularity of supply over time) and food safety (quality of products, including contamination by toxic chemicals, germs and, in general, nutritional balance and quality of nutrients). Advice and the corresponding agrometeorological communication issues could be treated systematically according to the product (commodity), step in the food chain, data requirements and other criteria.

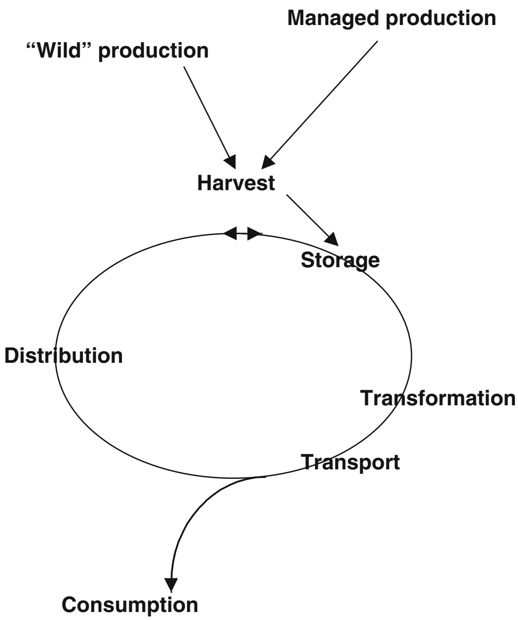


Fig. II.1 Agrometeorology deals with all the weather-sensitive components of the food chain, from production to consumption of all agricultural products, specifically including animals and plants (after Gommes 1998a)

It is interesting to observe that the "communication" of information and knowledge can be described very much along the same lines as the Fig. II.1, as the messages have to be produced and collected, stored and eventually used. With the development of the climate change "problematique", the analogies are reinforced by the fact that farming is not only a victim of climate change, but also one of its causes!

It has been the ambition of most farmers in the world to limit the impact of weather and climate on their production. This was achieved from the early civilisations through irrigation and flood recession cropping. In many developed countries, we witness a tendency to use technology to reduce dependence on weather, as in greenhouses or air-conditioning of buildings and tractors. To a large extent, the fact that many farmers in developed countries practise preventive control of pests and diseases by systematically resorting to pesticides and other inputs is also a way to abstract, as much as possible, farming from weather. Preventive phytosanitary treatments allow the producers to decide the time of their interventions, which otherwise would be determined by environmental conditions conducive to the development of pests and diseases. Warning systems, one of the best established forms of agrometeorological communication, have the potential to reduce the cost of farming, but they also entail some risks making farmers' planning more difficult (Rijks and Baradas 2000).

As a result, less environment friendly farming in combination with little reliance on farm advice is often regarded as less risky: even when farmers have been using weather forecasts directly for a number of years to plan their operations. Models, however, have not really entered the farm in spite of their potential. The main causes seem to be a mixture of lack of confidence and lack of data (Rijks 1997). Most of the times, lack of confidence is caused by the lack of data. This is the reason why very simple approaches like "response farming" (see Sect. II.D.9.b below) do have a great potential but in reality are not frequently applied. For examples see earlier in Part II of this book. The same reasoning can apply to crop insurance: great potential but lack of confidence due to the lack of data.

II.D.4.b Different Perceptions of Weather

In some cases, the perception of the same weather event is different for the expert and for the farmer. In Jamaica, for example, the mid summer dry-spell (MSD) is the most critical climate obstacle towards crop productivity for local farmers (Allen et al. 2008). The MSD is related to both local and remote factors that contribute to unfavourable precipitation patterns by limiting tropical convection. The MSD is evident in both farmer perception through extensive surveys and through a remotely sensed lagged vegetation response. However, the favourable 29-year climate trend contradicts negative farmer perception. This difference between perception and trend can play a significant role towards climate related policy by elaborating a long term (2–3 month) forecast suited for farming needs resulting from direct farmer input.

In other cases farmers' perceptions of climatic variability are in line with climatic data records (Gbetibouo 2009) as farmers in the Limpopo River Basin of South Africa have appreciation for temperature's increase and the related reduction of rainfall. Farmers with access to extension services are likely to perceive changes in the climate because extension services provide information about climate and weather. Having access to water for irrigation increases the resilience of farmers to climate variability; therefore, they do not need to pay as much attention to changes in the patterns of rainfall and temperature.

With more experience, farmers are more likely to perceive change in temperature. Although farmers are well aware of climatic changes, few seem to take steps to adjust their farming activities. In this case study, only approximately 30% of farmers have adjusted their farming practices in order to take into account the impacts of climate change. The main adaptation strategies of farmers in the Limpopo River Basin are switching crops, changing crop varieties, changing planting dates, increasing irrigation, building water harvesting schemes, changing the amount of land under cultivation, and buying livestock feed supplements.

II.D.5 "Client Centred" Communication

Communication does not serve to disseminate the "instructions" of the research or extension worker, but to channel adequately focused information to help farmers to master field management skills and also to feedback farmers constraints and findings in order to sustain a permanent dialogue with all partners. The practical methods or channels that can be used for the actual dissemination of agrometeorological information depend on the client to be reached and the sender as well as the format of the message or information. The communication channels can be broadly divided into three groups, namely mass and electronic media, group methods, and individual contacts. In general, the use of more than one channel gives a greater chance of reaching the client or user. The individual contacts can be time consuming but also build good rapport and help maintain credibility between the role-players.

In identifying the clients, it is often useful to focus on a specific homogeneous target group likely to have sufficiently similar needs and, therefore, can also benefit from similar information and specific communication approaches (Rijks and Baradas 2000; Stigter et al. 2007). This target group may not be existing groups, as such, but more a category of clients or farmers who would be able to identify similar weather dependent decisions. Therefore, the same sort of uniform recommendations, advisories, or information can be formulated to address these critical decisions and provide the desired weather and climate information using the same format and language, etc. The group methods include the use of already existing farmer groups, such as alumni of climate field schools (Winarto et al. 2008), or other interest groups such as co-operatives, growers association, seed producers network, etc.

The client centred communication also provides face-to-face contact with people who are the clients and enables the agrometeorologists to obtain more specific feedback from groups of users concerning the information provided. This is a way of making better use of scarce human resources, and groups can meet on a regular basis. Group meetings can be informal or formal, a discussion, or formal farmers' days of information meetings. There are advantages for both the farmers and for the extension staff. The groups allow farmers to be exposed to other farmers' successes as well as to realize that they may encounter similar problems or obstacles.

The client centred approach encourages the groups or networks to preserve and to consider alternatives that may have been used by others within the clientele group.

It also helps to share experiences and opinions and identify gaps in the knowledge or information flow (Joyce 2003). Groups can also commit together to take certain action and then support each other throughout the process (Bembridge 1991). The groups can be used in follow-up to both mass media and individual contacts. The use of mass media for communication of agrometeorological information has the advantage of reaching many more people with each action (e.g. Stigter et al. 2007).

Participatory methods are required to meet farmer needs in less productive and highly variable environments (Witcombe 1999; Roncoli et al. 2009) helping to make better informed farm decisions (Hartmann et al. 2002) through targeted communication. The Farmer Field School (FFS) approach is a direct response to support improved access to learning about integrated farm management of the farming communities. As a result of a Participatory Assessment and Planning (PAP) exercise, the farming communities indicate their priorities for technical information particularly in relation to agrometeorological management, improving the efficiency of planting, fertiliser use, increasing output and controlling costs.

The FFS approach underlines the following key concepts and principles (Hellin and Higman 2001; Ortiz et al. 2004; Tripp et al. 2005; Mancini and Jiggins 2008):

- Farmers are experts: farmers learn by carrying out for themselves the field studies/comparisons related to the particular farming practice, they are interested in “learning by doing”;
- Field based education: real live examples in the field (farmer domain) is the primary learning material. Farmers interact in small sub-groups (10–15 farmers) to collect and analyse data and perform action. Farmer driven research should be responsive to field needs as part of the research network and supporting educational programs;
- Decisions based on farmer analyses and shared with others in the group for further discussion, questioning, and refinement;
- Extension workers are facilitators, not teachers: extension workers only offer guidance to farmer projects (mainly principles but no packages nor atomised messages);
- Problem posing/problem solving: problems/challenges confronted in the field along the season are tackled in real-time using numerous analytical methods within farmer groups;
- Holistic approach integrating all technical, ecological, socio-economic and educative aspects;
- Group dynamics within farmer teams for skill building in communication, problem solving, leadership towards higher quality of farmers, farm management skills.

II.D.6 Contents of Agrometeorological Messages

The substance of the agrometeorological message is twofold: (1) to help farmers avoid the negative effects associated with climate variability and (2) assist them in making optimal use of available resources, this including climate resources per se (solar radiation, heat, water), but also the financial mechanisms available under the MEAs. Details about specific variables are given in Sect. II.D.7 below.

Climatic conditions and anthropogenic factors (e.g. those associated with increased pressure on the land) mutually reinforce chronic vulnerability to climate variability and natural disasters. Technology, on its own, is at best a partial solution. Technological solutions (including communication) should be embedded in the relevant social and environmental contexts. Neither an agricultural nor any other single sectoral intervention alone can provide sufficient scope to manage the risks associated with climate change and variability. Short-term and long-term adaptive measures in agriculture, linked with clear focus on possible future risks, must be integrated into cross sectoral planning.

The list below provides a schematic overview of the technical areas in which agrometeorological communication is relevant. Most items can be categorised as "emergency" and "non-emergency". It is more or less arbitrarily subdivided into "awareness and risk management", "societal and institutional adjustment", "improved practices" and "short and long term planning". The earlier examples of agrometeorological services in this Part II illustrate many of these areas.

Awareness and risk management

- Awareness creation and advocacy on risk management, linking them with climate change and adaptation issues;
- Strengthening of community resilience, including local institutions and self-help capacities;
- Non-emergency advice on how to maximise the use of climate resources (orient the rows NS or EW), plough along elevation contours, plant after rain starts, avoid swamps with cattle in August, adopt mulching and conservation agriculture very gradually and crop insurance;

Societal and institutional adjustment

- Socio-economic adjustments (livelihood diversification, market facilitation etc.);
- Strengthening of formal institutional structures and environment;
- Policy formulation to catalyse enhancement of adaptive livelihood opportunities;
- Introducing alternative enterprises/farming systems, such as agroforestry;
- Risk mapping, to know how/where to target the communication. "The notion of risk communication refers to a social process by which people become informed about hazards, are influenced towards behaviour change and can participate in decision making about risk issues" (Rohrmann 2000);

Improved practices (adaptation to climate variability)

- Physical adaptive measures (e.g. link canals, irrigation, water harvesting, storage facilities for retaining water, microclimate manipulation, drainage, increased soil carbon concentrations);
- Adjustment of existing agricultural practices to match anticipated risks (e.g. adjustment of cropping pattern, selection of adapted varieties of crops, diver-

sification of cropping and/or farming systems, better storage of seeds and fodder, dry seed beds, switch to alternative crops, more efficient use of irrigation water on rice paddies, more efficient use of nitrogen application on cultivated fields, improved water management including water harvesting);
- "Tactical" day to day planning of farm operations;

Short and long term planning

- Current weather warning: frost tomorrow morning, too much wind for spraying pesticides;
- Longer term weather warning (early warning systems);
- Seasonal and decade-long forecasts for planning of operations and warning;
- Climate change impacts for targeting government interventions (10 years from now and beyond);
- Knowledge e.g. about options available to countries under Multilateral Environmental Agreements (MEAs) such as the UNFCCC, UNCCD etc.

While it is relatively easy to define technical messages that can be communicated, we have to look beyond "adaptation to current climate variability" and target the basic vulnerability factors of rural communities. Communication also aims at improving the learning process and creates the capacity to cope with climate variability.

This is particularly relevant in the current period of rapidly changing variability patterns, which are probably best approached from the broader ecosystem perspective. In pursuing this goal, agrometeorological communication should focus on support for the decision making and capacity building processes that shape social learning, technology adaptation, innovations and development pathways. This process of adaptation needs to explicitly address the needs of poorer farmers and marginalized groups that are most vulnerable to the types of climatic and socio-economic changes that are likely under perturbed climates. Agrometeorological services as defined in Part I of this book and exemplified earlier in this Part II can be used in this support.

Efficient communication also needs institutional capacity building and strengthening of organizational networks across all levels and sectors as a basic precondition (e.g. Stigter 2006). The experiences clearly show that provision of a comprehensive approach with concrete roles for action is necessary to motivate change in local perceptions and ensuring meaningful interventions through local service providers including government institutions. A lot can actually be achieved with a full buy in and work though the existing institutions, if everybody involved gains from the new roles.

II.D.7 Role of Data, Information and Knowledge in Customizing Communication Products

Applied agrometeorology advocates communication of a variety of information and knowledge available through varied sources ranging from scientific techniques to local indigenous knowledge for farm decision making. Most difficulties in decision making become apparent with the identification and recognition of available alternatives, the determination of relevant data, and collecting of relevant information (Backus et al. 1997). Building an improved data base of climatological, meteorological, phenological, soil and agronomic information is a priority to operationalise communication approaches at the farm level.

Apart from the above category of data, additional information on land characteristics, cropping systems, institutional services and support services are necessary. Institutional and Support Services perform most important functions of observing, monitoring, archiving, analysis, communicating reliable data and information to the required agencies and to end users. The development of these databases usually is dependent on the availability of institutional and technical capacity, which very often is weak due to low level vocational education systems (e.g. Stigter 2006).

The typical meteorological and climatological data are in most of the cases maintained by the NMHSs. These data sources are rarely used by the department of agriculture or agriculture extension professionals, while these are the major source of information on latest technologies on agriculture. Applied agrometeorology advocates that the essential part of these data bases be available at the local level within the reach of information providers in agriculture, livestock, forestry and fishery sectors. Modern data sources like remote sensing and satellite imagery deliver additional data on land use, land cover, vegetative index, cloud cover, sea surface temperature, etc., providing more details for developing value added information products to farmers. The general data requirements, their sources and intended purposes are exemplified in Table II.1.

II.D.8 Facilitating Effective Communication Through Indigenous Knowledge

Existence of indigenous knowledge about weather and climate as well as on coping with risks motivates farmers to know more and act on their decisions. "Local" or indigenous knowledge is an integral part of the culture and history of every local community or society. It is essential to build communication approaches on the existing indigenous knowledge on weather and climate and management alternatives (e.g. Stigter 2007). See also Chaps. IV.4 and IV.9.

The process of incorporating new information into the indigenous knowledge base is iterative (Pinners and Balasubramanian 1991) and the approach could be used to combine the local knowledge base with suitable climate information for effective communication. Indigenous knowledge is commonly held by communities rather than by individuals. Indigenous knowledge is the basis for local-level decision making in agriculture, natural resource management, and a host of other activities in communities.

Farmer's best merge "new" scientific and technical information at field level: testing and practising themselves is one of the most efficient ways to convince

Table II.1 Categories of data required for customizing communication products, their potential sources and examples of intended use for agrometeorological applications and services

Category	Types of data	Potential source	Examples of intended use for agrometeorological applications and services
Meteorological and climatological	Historical daily/decad/monthly data on precipitation, temperature (max, min) solar radiation, relative humidity, evaporation etc.	National Hydro-Meteorological Services, meteorological agencies, agrometeorological centres and universities	Evaluations of water supply, water requirement calculations, dates of onset and cessation of the rainy season, dry spells, rainfall intensity, water balance
	Wind speed and direction	Meteorological and agrometeorological centres	Designing windbreaks and shelterbelts
	Leaf wetness, temperature and relative humidity	Agromet stations	Pests and disease incidence
Land and soil	Land slopes, surface drainage, water table	Geological department, public works, land and water resources, river authority	Land suitability, water source and availability
	Soil properties (depth, texture, structure, fertility, water holding capacity, available water, salinity, acidity and other problems)	Soil research institute, agriculture department, soil testing laboratory, national soil bureau	Water balance, water stress characteristics, fertilizer recommendations
Crops and cropping systems	Crops, varieties, duration, monocropping, mixed-, relay-, inter-cropping systems	Department of agriculture	Matching crops and cropping systems with the rainy season; crop and varietal choice decisions
Agronomic management	Time of sowing, planting, quantify and time of fertilizer application, weeding, thinning, row width, method of irrigation, pest and disease control measures, time and method of harvesting	Department of agriculture, community representatives, farmers surveys, focus group meetings	Developing management alternatives, planting time, plant population, row spacing, fertilizer application options
Socio-economic and market information	Livelihood groups, livelihood objectives, risk perception, market demand, access to credit, inputs, commodity price etc.	Community representatives, key informants, local institutions, community based organisations, etc.	Input optimisation, identification of target groups within the community, crop and varietal choice

Table II.1 (continued)

Category	Types of data	Potential source	Examples of intended use for agrometeorological applications and services
Institutions	Availability of enabling institutions, mandates, structure, facilities, technical capacity, technical advice, access to support (transport, market), local cooperatives, micro financing etc.	National level relevant ministries, departments	Identification of focal agencies for implementing agrometeorological products and services and their relevance to contribute to the overall processes

farmers. However, group discussions at community level facilitate understanding and sharing of experiences among community members. Other partners involved in the convincing process include:

- Intermediaries as farmer advisers: mainly the agricultural extension services but also officers of agricultural co-operatives, input suppliers, woman organisations which provide technical and economic advisory services to farmers;
- Researchers develop and provide updated information used by advisers at national and regional level, but sometimes also directly to farmers, particularly within research and development farmer networks.

Much of the research and development needed for less-favoured lands does not involve high science, but rather the spread and adaptation of indigenous knowledge and practical innovations. NGOs have been very successful in pursuing this agenda and in working with local communities to overcome social and institutional constraints. There is a need for more participatory approaches for structuring innovative communication approaches and test new technologies which shall be adopted by the small farmers (Roncoli et al. 2009).

II.D.9 The Role of Technology

II.D.9.a Case Studies

A very extensive inventory of the uses of Information and Communication Technology (ICT) to provide farmer advisories in Africa by Gakuru et al. (2008) concludes that there will never be a “one fit for all” system. But the report suggests that systems which use a voice-platform or audio files provide an innovative and promising entry point to farmer information, while the other platforms (SMS and web-based platforms, see Li et al. 2008) remain essential to provide a back-end, offering more detailed information.

In September 1999, a World Bank funded workshop titled "Users responses to seasonal climate forecasts in southern Africa: what have we learned" was convened in Dar es Salaam, Tanzania. The objective was to present, discuss and compare meteorological research, primarily in relation to the agricultural sector in southern Africa. Two aspects came out as significant for sustainable agricultural production and food security. The first was that there were communication barriers and that there is need to develop appropriate information channels. The second was that there were bottlenecks in the effective use of seasonal climate forecasts by farmers (Cicero Report 1999; see also Meza et al. 2008 and Chap. IV.12). In any agricultural development programme, effective communication is a requirement to success. In the case of seasonal climate forecasts, users frequently have not been able to "decode" the information disseminated (e.g. Stigter 2007).

In a survey conducted in villages in Phaswana in South Africa, Bembridge and Tshikolomo (1998) found that among the respondents, 92% owned radios, 52% owned television sets and 32% were connected to telephone facilities. With regard to television and telephone facilities, the survey results may not be representative of the situation in southern Africa given the relative economic advancements of South Africa. However, the survey provides basic information that target audiences in South Africa have access to electronic media.

Being in possession of a television or radio does not guarantee understanding of information through these media, but the survey demonstrated that farmers in South Africa make use of electronic media as sources of agricultural information. Electronic media can potentially be reliable channels to communicate seasonal climate information as long as appropriate terminology is applied to ensure shared meanings. However, the fact that information has been disseminated does not necessarily mean that communication has taken place.

The Bembridge and Tshikolomo (1998) survey ascertained how the respondents obtain information for agricultural management. They found that 46% of the respondents had access to written information, mainly in the form of popular journals with little research-based information. The majority of the respondents (76%) claimed to listen to radio broadcasts on farming, but indicated that the information did not contain technical information for farm management. The information was of a general nature. The same was claimed regarding information through television. Respondents also obtained information from other farmers, farm demonstrations and government and corporate extension officers.

Farmers obtain information for farm management from printed media (newspapers, journals, etc.) and electronic media (radio and television). Rural radio is a major source of information for the farming community in developing countries (e.g. Stigter et al. 2007). This may be true for meteorological information as well (Gommes 1992, 1998b, 2001). They also have other sources of information, including farm demonstrations, farm discussions, farmers' days, meetings with other farmers, government extension and corporate extension. Among these media, the most popular is radio (76%), farm demonstrations (72%), farm discussions (58%), and other farmers (56%).

The least contacted source is government extension officers. The reason for the low level of interest in government extension officers as sources of agricultural information could be the low training level of the officers (Mukhala and Groenewald 1998) or their attitudes (Stigter 2006). Exceptions to this rule are the intermediaries in charge of agrometeorological services as exemplified in the earlier parts of this Part II, but the problems discussed in intros II.A and II.B hint among others at these same issues.

Similar examples can be found in other parts of Africa (IAC 2004). An example is the "Mapping of Pastoral Movements in the Sahel", where the population has access to information on how to use their pasture resources effectively during the dry season. Tools such as Geographic Information Systems (GIS), Global Positioning Systems (GPS) and thematic maps of seasonal movements of livestock reinforce the identification of relevant know-how. Effective methods of livestock farming incorporating information and communications technology are identified. These help to reduce conflicts between growers and breeders and to alleviate animal pressure on pasture lands, while enhancing the productivity of traditional livestock farming, with the direct consequence of increasing family income.

In India an experimental network connected more than 20 isolated rural villages to a wireless internet service. About half the population in most of these villages had a total family income of less than US$25 per month. The project aimed at providing knowledge on demand to meet local needs using information and communication technology, and it did so through a bottom-up process. Volunteer teams helped poll the villagers to find out what knowledge they seek.

Particularly popular were women's health information, advice on growing local crops and disease control, the daily market prices for these crops, local weather forecasts, and information about government programs to aid poor families. An expanded concept of a global electronic network was envisioned to connect scientists to people at all levels – farmer organizations and village women, for example. The project intended to demonstrate that empowering people through access to timely and relevant information can make a difference in the life of the rural poor, and that new information and communications technology can play a crucial role in this effort. A unique feature of the project is the fact that most information is collected and fed in by the local community (from IAC 2004).

As with breeding and biotechnology, information technology can assist agricultural production practices to overcome the gaps between the actual and attainable yield and between attainable and potential yield, and to increase the potential yield level. Rapid, effective information processing and management can help agriculture. Some examples are resource allocation, crop and animal production modeling and improved resource-use efficiency. In addition there is a strong need for risk-reducing information such as for the Sahelian zone, as mentioned above for livestock movements.

Agro-ecological analyses may reveal substantial production potentials (Bindraban et al. 1999, 2000), but risk-reducing information is vital for farmers considering use of new technologies, such as drought tolerant crops (Jagtap and Chan 2000). Decision support systems for strategic and tactical (operational) decision making are needed to supply such information. The whole arsenal of new information and communication technologies, such as remote sensing, GIS and crop and climate modeling, can be employed for this purpose (see Chaps. IV.17, IV.18, IV.19 and IV.20).

II.D.9.b Farm Adaptive Dynamic Optimisation (FADO)

FADO is a technologically sophisticated approach that basically constitutes a modernization of response farming, a concept developed by Stewart (1988) in the seventies and applied in its original form in a number of countries [see also Part I and http://responsefarming.org/]. The FADO philosophy underlies the experience of the Australian work on Whopper Cropper (see for details the site http://www.apsru.gov.au/apsru/Products/Whopper/NationalWhopperCropper.pdf) developed, among others, by the Queensland Department of Primary Industries. Based on the above-mentioned Southern African, Sahelian and Indian experience, FADO may now be considered a technically feasible approach, which, however is rarely implemented in developing countries. FADO finds its justification, among others, in the fact that subsistence agriculture is expanding more and more into marginal areas, with at least some intensification taking place. Smallholders face the problem of further degrading their environment, increasing variability of their production, while at the same time having to produce more in a context of growing populations and increasing urbanisation.

FADO aims to develop advisory services to help farmers stabilise their production and income by making better use of environmental resources, such as climate (rainfall, sunshine), soil etc. The advice is based on local farming, historical weather data (risk assessment) and actual current season weather conditions. In practice, information on rainfall, planting dates etc. is systematically collected in real-time from villages, analysed centrally and then management options are fed back to the village, tailored to local conditions. The concept of FADO is very relevant in the present context, as it entails two-directional flow of information and the intensive use of communication and data processing technology.

FADO (Fig. II.2) includes the following steps/components: (1) collect real-time local, village-level weather and crop (e.g. phenology) information and transmit them to a central location, for instance the National Agrometeorological Service; (2) simulate management options based local conditions (e.g. soil, farming practices) and market data (crop and input prices); (3) feed back the advice/management options to the village. The advice is based on local farming (crops, soil, practices), local historical weather data (risk assessment) and actual local current season weather conditions, taking into account seasonal weather forecasts (Meza et al. 2008) and historical local climate risk.

The technology to implement the steps above (optimisation of local decision making) now exists, including downscaling and the preparation of local data

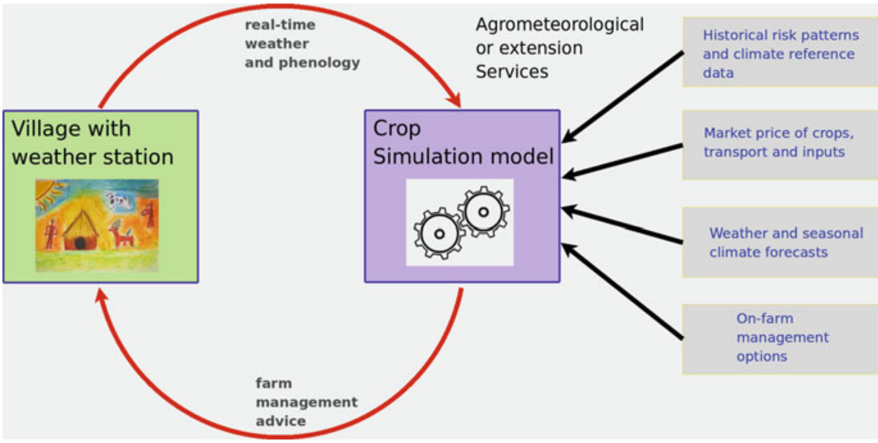


Fig. II.2 Data flow in a Farm Adaptive Dynamic Optimisation (FADO) system. Source of African village drawing: http://www.ec-freinet-acheres.ac-versailles.fr

(Bernardi et al. 2006; Wratt et al. 2006), models for decision support (Orlandini et al. 2008), including fertilizer management (Kersebaum et al. 2005) and farm nutrient management in a participatory context (Cabrera et al. 2008), the use of climate forecasts (Everingham et al. 2008) and the net-based tools for data dissemination, including maps. Basically three categories of applications of FADO can be identified (Gommes 2001):

- What-if experiments to optimise the economic return from farms, including real-time irrigation management. This is the main application and the only area where models are well established, including in some developing countries (Smith 1992) (There are good case study illustrations in this Part II)
- Optimisation of resources (pesticides, fertilizer) in the light of increasing environmental concerns (and pressure);
- Risk assessments, including the assessment of probabilities of pest and disease outbreaks and the need to take corrective action.

Providing agrometeorological information and services as part of building agricultural based livelihoods in a post conflict country presents new challenges which have not been addressed adequately by the latter professionals. The climate does not recognise post-conflict communities and hence they are subjected to the same environment, as they try to rebuild their lives. What are the best methodologies to provide them with agrometeorological information in order for them realise reasonable yields and production?

Southern Sudan is one such a case (see for comparable details Box III.2.7. in Sect. III.2.1.(e)), the extension system is almost non-existent, the motivation for government staff is also low. FAO is putting in place agrometeorological stations and data have started flowing. The challenge is to provide such information and services to the target audience. These are the circumstances that demand a well thought agrometeorological information communication strategy.

II.D.10 Capacity Building for Effective Communication

It is increasingly acknowledged that the complexity of agricultural development demands an array of technological solutions and service structures, including a readiness to adapt and change these management alternatives, as situations change and understanding increases (Walker 2005). In "demand-driven" communication approaches, farmers are being viewed as "clients" for whom agrometeorological information and services need to be tailored. The definitions and roles of extension officers and extension agencies are changing, especially because of the need to cover the information and training needs of a diverse, heterogeneous clientele.

Agricultural Extension Services are being reoriented in order to respond to the need for participation by a wide range of stakeholders, to improve responsiveness and accountability, and to include non-conventional messages that incorporate environmental issues. Main orientations are: (i) Decentralised and open to multiple delivery mechanisms, including delivery by private-sector enterprises, NGOs and producer associations and (ii) Respond to tremendous differences in needs and priorities among farmers according to their access level to resources, social and gender status (e.g. Stigter et al. 2007).

Within the key approach to establishing a farmer centred decision making process at the community level, an educational approach appears essential to stimulate adapted use of improved technologies in developing countries. Targeted capacity building initiatives are an essential component of the communication process (Table II.2) [See also Chap. IV.5.]

II.D.11 Monitoring and Evaluation of Communication Approaches

Monitoring and evaluation of the effectiveness of communication in agrometeorology need to be a continuous process. Monitoring is a continuous process, while evaluation is performed periodically to measure the impact of communication approaches: both need to involve users and providers of information and services. Monitoring and evaluation need to answer the following key questions:

- Has the information reached the user?
- Has the user used the information?
- Has the information been helpful (by how far)?
- What feature the user did like or dislike about the delivery system?
- What improvement the users would suggest?
- How can diverse types of agrometeorological data be integrated into useful information that responds to the often dissimilar application needs of farming communities?

Table II.2 Level of operation of clients, the target groups and examples of contents of the demand driven capacity building for client centred communication

Level of operation of clients	Target clients	Capacity building for communication targets
Agrometeorological service	Agrometeorological services providers with the agency responsible for Agrometeorology and/or Hydrometeorological Services staff responsible for communicating climate/weather information along with options	– interpretation of regional and national forecast products; – analysis of location specific risks related to climate phenomena; and – communication of information to the relevant sectoral agencies
Extension at the head quarters	Agricultural extension officers and responsible officers for livestock and fisheries as service providers	– development of impact outlooks relevant to agriculture and allied sectors – preparation of alternative management practices in response to forecasts
Extension at the decentralised level	District/provincial extension officers; sub-district extension officers; intermediaries and service providers	– communication and use of climate/weather information – mobilising resources in response to the climate/weather information
Farmer and community level	Intermediaries, community representatives, community leaders; CBO representatives; developmental NGOs; farmer groups, farmer cooperative representatives	– mobilising the members and/or farmers to respond to the risks associated with the forecast information

- What type of information is needed by diverse groups of end-users, given their different farming socio-economic and cultural systems?
- Which are the appropriate communication technologies for each social group?

Impact of information on local farm output by surveys and/or focus groups should provide a quantitative basis to improve information and services and their communication systems. Effectiveness and use of climate information and services can be improved through close collaboration and co-ordination among the relevant agencies and organizations, National Extension Services, National Agrometeorological Services, specialized NGOs and farming communities (Weiss et al. 2000).

II.D.12 Conclusions

Agrometeorological communication addresses all weather dependent aspects of crop and animal production, food and non-food forest products, as well as fisheries.

It aims at improving or stabilising production or income through the exchange of "messages" (data, information, knowledge), with feedback, between a "producer" and a "target" or "audience". Types of audiences (clients) vary a lot and the messages must be customized and refined by experience to achieve maximum impact. This also applies to the communication media. As to their contents, agrometeorological messages can vary from awareness creation and awareness advocacy to on-farm management advice, warnings, knowledge and information useful for planning at the level of individuals, institutions and government.

While efficient communication relies on reliable and up-to-date data and information, reference to and actual use of indigenous knowledge can lead to an easier adoption of the message. We stress that modern communications technology, including the internet and wireless telephones, offer tremendous potential to improve agrometeorological communication, such as the establishment of Farm Adaptive Dynamic Optimisation (FADO) schemes. FADO is based on the real-time collection of on-farm information such as weather and phenology and the off-site processing of the information in order to derive farm management options that are fed back to the village. We concluded by discussing training requirements and the need to systematically assess the effectiveness of agrometeorological communications systems.

A possible scheme to develop agrometeorological communication for development could adopt the following criteria: (1) a holistic approach that embraces the complexity of the system and its multiple stakeholders; (2) the acknowledgement that information and communication must be part of every stage of an intervention; (3) the recognition that the communication dimension is not simply about information and messages, but about two-way exchange of perspectives using a variety of methods and media; (4) the realization that all communication activities must be planned ahead, involve the multiple "world-views" of the different stakeholders, and include evaluation of their ways of learning and sharing; (5) the understanding that a combination of several communication functions will be necessary in any communication strategy and, eventually, the realization that the communication processes enable the sharing of information (meaning) and knowledge influencing vulnerability related factors.

Modern agrometeorology can resort to a number of sources of data and techniques of analysis and telecommunication including crop models, geographic information systems, stochastic weather generators, spatial interpolation techniques, wireless telephones and the internet. This results in the transmission of crop and weather data from the rural areas to the national agrometeorological services being now much easier than in the past.

However, transmitting local advice directly or in services to farmers, while often feasible technically, is too rarely done in practice. Exceptions are exemplified in this Part II. National Services responsible for agrometeorological communications should, therefore, optimise the use of human, institutional (including educational), technological and climate resources to develop deferred and real-time advice tailored to local (village) conditions and particulars, and ready for use by farmers.

References

Allen T, Curtis S, Gamble DW (2008) Remote climate forcings of Jamaica's midsummer dry spell and vegetative response. Eos Trans AGU 89(53). Fall Meet. Suppl., Abstract A13A-0211 at: http://adsabs.harvard.edu/abs/2008AGUFM.A13A0211A

Backus GBC, Eidman UR, Dijkhuigen AA (1997) Farm decision making under risk and uncertainty. Neth J Agric Sci 45:307–328

Bembridge TJ (1991) Practice of agricultural extension – A training manual. Development Bank of South Africa, Halfway House 1685, Gauteng, 279pp

Bembridge TJ, Tshikolomo KA (1998) Communication and decision making among fruit growers in the Phaswana area of Northern province. S Afr J Agric Ext 27:19–29

Bernardi M, Gommes R, Grieser J (2006) Downscaling climate information for local disease mapping. Parasitol 48:69–72

Bindraban PS, Verhagen AJ, Uithol PWJ, Henstra P (1999) A land quality indicator for sustainable land management: the yield gap. Report 106. Research Institute for Agrobiology and Soil Fertility, Wageningen, 22pp

Bindraban PS, Stoorvogel JJ, Jansen DM, Vlaming J, Groot JJR (2000) Land quality indicators for sustainable land management: proposed method for yield gap and soil nutrient balance. Agr Ecosyst Environ 81:103–112

Blench R, Marriage Z (1998) Climatic uncertainty and natural resource policy: what should the role of government be? Natural Resources Perspectives 31, ODI, London, 4pp

Cabrera VE, Breuer NE, Hildebrand PE (2008) Participatory modeling in dairy farm systems: A method for building consensual environmental sustainability using seasonal climate forecasts. Clim Change 89:395–409

Cicero Report (1999) Published by Centre for International Climate and Environmental Research, University of Oslo, Sweden. 52 pp. www.cicero.uio.no/publications/annualreports/a1999.pdf

Everingham Y, Baillie C, Inman-Bamber G, Baillie J (2008). Forecasting water allocations for Bundaberg sugarcane farmers. Clim Res 36:231–239

Gakuru M, Winters K, Stepman F (2008) Inventory of innovative farmer advisory services using ICTs. Forum for Agricultural Research in Africa. Entebbe, 67pp. http://www.fara-africa.org/media/uploads/File/

Gbetibouo GA (2009) Understanding farmers' perceptions and adaptations to climate change and variability. The case of the Limpopo Basin, South Africa. Discussion Paper 00849, IFPRI, Washington, 48pp. http://www.ifpri.org/pubs/dp/IFPRIDP00849.pdf

Gommes R (1992) Applications agrométéorologiques pour le petit exploitant agricole. [Agrometeorological applications for small farmers.] Proceedings Francophone Workshop on "Rural Radio and Diffusion of Agrometeorological Information", Bamako, 18–22, WMO/CTA, Geneva, pp 29–37

Gommes R (1998a) Some aspects of climate variability and food security in sub-Saharan Africa. In: Proceedings International Conference on "Tropical Climatology, Meteorology and Hydrology", Brussels, 22–24 May 1996. Royal Meteorological Institute of Belgium and Royal Academy of Overseas Science, Brussels, pp 655–673

Gommes R (1998b) FAO's experience in the provision of agrometeorological information to the user community. In: Proceedings International Workshop on "User Requirements for Agrometeorological Services", Pune, 10–14 November 1997. IMD, Shivajinagar, Pune, pp 53–77

Gommes R (1999) Roving seminar on crop-yield weather modelling; lecture notes and exercises. WMO, Geneva, 153pp

Gommes R (2001) What can modern agricultural meteorology do for the subsistence farmers? Paper Presented at the 1st International Workshop on Farm Radio Broadcasting, 19–22 February, FAO, Rome, 11pp. http://www.fao.org/docrep/003/x6721e/x6721e00.htm#TopOfPage

Gommes R (2003) Specification for a database of extreme agrometeorological events. In: Das HP, Adamenko TI, Anaman KA, Gommes RA, Johnson G (eds) Agrometeorology related to extreme events. WMO Technical Note 201 (WMO 943), Geneva, pp 123–134

Hartmann H, Pagano TC, Sorooshian S, Bales R (2002) Confidence builders: Evaluating seasonal climate forecasts from user perspectives. Bull Am Meteorol Soc 83:683–698

Hellin J, Higman S (2001) Competing in the market: Farmers need new skills. Approp Technol 28(2):5–7

IAC (2004) Realizing the promise and potential of African agriculture: science and technology strategies for improving agricultural productivity and food security in Africa. IAC Secretariat, Amsterdam. XXX + 266pp

Jagtap SS, Chan AK (2000) Agrometeorological aspects of maximum temperature and precipitation in the sub- humid and humid zones of Africa and Asia. Agr For Meteorol 103: 59–72

Jarvis CH, Stuart N, Hims MJ (2002) Towards a British framework for enhancing the availability and value of agrometeorological data. Appl Geogr 22:157–174

Joyce LA (2003) Improving the flow of scientific information across the interface of forest science and policy. For Pol Econ 5:339–347

Kersebaum KC, Lorenz K, Reuter HI, Schwarz J, Wegehenkel M, Wendroth O (2005) Operational use of agro-meteorological data and GIS to derive site specific nitrogen fertilizer recommendations based on the emulation of soil and crop growth processes. Phys Chem Earth 30(1–3, Spec Iss):59–67

Li Z, Qian J, Li M, Liu D, Yang X (2008) Agrometeorological information publication system based on ArcIMS. Trans. Chin Soc Agric Engn 24(2, suppl):274–278

Mancini F, Jiggins J (2008) Appraisal of methods to evaluate farmer field schools. Devel Pract 18:539–550

Meza FJ, Hansen JW, Osgood D (2008) Economic value of seasonal climate forecasts for agriculture: review of ex-ante assessments and recommendations for future research. J Appl Meteorol Climatol 47(5):1269–1286

Mukhala E (2000) Meteorological services and farmers in Africa: Is there shared meaning? http://www.fao.org/sd/cddirect/cdre0051.htm.

Mukhala E, Groenewald DC (1998) Experiences and perceptions of Black small-scale irrigation farmers in the Free State. S Afr J Agric Ext 27:1–18

Oerke EC, Dehne HW, Schoenbeck F, Weber A (1994) Crop production and crop protection: estimated losses in major food and cash crops. Elsevier, Amsterdam, 830pp

Orlandini S, Massetti L, Marta AD (2008) An agrometeorological approach for the simulation of Plasmopara viticola. Comput Electron Agric 64:149–161

Ortiz O, Garrett KA, Heath JJ, Orrego R, Nelson RJ (2004) Management of potato late blight in the Peruvian highlands: evaluating the benefits of farmer field schools and farmer participatory research. Plant Dis 88:565–571

Pinners E, Balasubramanian V (1991) Use of the iterative diagnosis and design approach in the development of suitable agroforestry systems for a target area. Agrofor Syst 15:183–201

Rijks D (1997) Feedback between yield forecast and farm operations: A matter of weight? In: Crop yield forecasting methods. Proceedings of an EU (DG VI, JRC Ispra and Eurostat) and FAO Seminar, 24–27 October 1994. Office Official Publications of the European Communities, Villefranche-sur-Mer, pp 41–44

Rijks D, Baradas MW (2000) The clients for agrometeorological information. Agr For Meteorol 103:27–42

Rohrmann B (2000) A socio-psychological model for analyzing risk communication processes. Aust J Disast Trauma Stud 2:150–166. http://www.massey.ac.nz/∼trauma/issues/2000-2/rohrmann.htm

Roncoli C, Jost C, Kirshen P, Sanon M, Ingram KT, Woodin M, Somé L, Ouattara F, Sanfo BJ, Sia C, Yaka P, Hoogenboom G (2009) From accessing to assessing forecasts: an end-to-end study of participatory climate forecast dissemination in Burkina Faso (West Africa). Clim Change 92:433–460

Smith M (1992) Cropwat, a computer programme for irrigation planning and management. Irrigation and Drainage Paper 46. FAO, Rome, 126pp

Stewart JI (1988) Response farming in rainfed agriculture. Wharf foundation press, Davis, California, x + 103pp
Stigter K (2006) Scientific research in Africa in the 21st century, in need of a change of approach. Afr J Agric Res 1:4–8
Stigter CJ (2007) From basic agrometeorological science to agrometeorological services and information for agricultural decision makers: a simple conceptual and diagnostic framework. Agr For Meteorol 142:91–95
Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi YM (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York etc, pp 171–190
Tripp R, Wijeratne M, Piyadasa VH (2005) What should we expect from farmer field schools? A Sri Lanka case study. World Dev. 33:1705–1720
Walker S (2005) Role of education and training in agricultural meteorology to reduce vulnerability to climate variability. Clim Change 70(1–2):311–318
Weiss A, Van Crowder L, Bernardi M (2000) Communicating agrometeorological information to the user community. Agr For Meteorol 103:185–196
Whitman RF, Boase PH (1983) Speech communications: principles and contexts. Macmillan, New York, 442pp
Winarto YT, Stigter K, Anantasari E, Hidayah SN (2008) Climate field schools in Indonesia: coping with climate change and beyond. Low Ext Input Sust Agric (LEISA) Mag 24 (4):16–18
Witcombe JR (1999) Do farmer-participating methods apply more to high potential areas than to marginal ones? Outl Agric 28:43–49
Wratt DS, Tait A, Griffiths G, Espie P, Jessen M, Keys J, Ladd M, Lew D, Lowther W, Mitchell N, Morton J, Reid J, Reid S, Richardson A, Sansom J, Shankar U (2006) Climate for crops: integrating climate data with information about soils and crop requirements to reduce risks in agricultural decision-making. Meteorol Appl 13:305–315
Yopp JJ, McAdams KC (1999) Reaching audiences. A guide to media writing, 2nd edn. Allyn & Bacon, Needham Heights, USA, 392pp
Ziervogel G, Cartwright A, Tas A, Adejuwon J, Zermoglio F, Shale M, Smith B (2008) Climate change and adaptation in African agriculture. Stockholm Environment Institute, Sweden, 54pp

Part II
Operational Applications of Agrometeorological Services

III.1 Introduction to Part III

Kees Stigter

Prabhakara Rao (Personal Communication 2008, see also http://farmersharakiri.rediffblogs.com) confirmed earlier sad stories that VRK Murthy (Personal Communication 2004/2005/2006) told me. In the words of Devinder Sharma, more than 300 farmers committed suicide in Andhra Pradesh (India) alone in 1 month of June 2004. This was the official death toll in the suicides register. Unofficially, the death toll was estimated to be much higher. The situation in several other states, including the frontline agriculture states of Punjab and Haryana, and even in the left-ruled West Bengal and Kerala is no better. Thousands of farmers have ended their lives in the past few years. What has baffled the governments is that the spate of suicides showed no signs of ending even after it announced a series of routine packages – free electricity and more credit – aimed at relieving farmer's misery. The package also includes an ex-gratia payment to the next of kin of the deceased, and money for a one-time settlement of the loans of indebted farmers. The erstwhile government too had started paying an ex-gratia grant to the affected families after suicides were initially reported in 1997–1998. After giving the assistance to some 250 farmer families, the payments were stopped on the plea that such an ex-gratia would prompt more farmers to take their lives. Recently Mohan Reddy Vishwavaram (2009) of the Hyderabad Water Forum reported still continuing suicides.

What is more depressing is that the governments are clueless of the reasons that forces farmers to commit suicides. Nor is there any effort from the so-called distinguished agricultural scientists, economists, and social scientists to come out with proposals to put an end to this shameful blot on the country's image. The reason is obvious. No one has the political courage to point a finger at the real villain, the industrial farming model that shifts the focus on cash crops and thereby plays havoc with sustainable livelihoods (Devinder Sharma through Prabhakara Rao, Personal Communication 2008).

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_6,

The small and marginal farmers, in tandem with the landless laborers, who constitute nearly 80% of Andhra's 80 million people, gave their verdict: the industry-sponsored economic reforms are anti-poor. In Karnataka too, where the farmers suicide rate is equally high, the over-emphasis on technology had only alienated a large percentage of farming populations from economic growth and development. Both the States had relied heavily on the British consultancy firm, McKinsey India Ltd., to draw the blueprint for economic reforms. In addition, McKinsey's services are also being utilised by West Bengal for re-designing the economic model of growth.

Blindly aping the World Bank model of agriculture (as suggested by McKinsey India Ltd.), Karnataka and Andhra pumped in huge finances to push in an industry-driven agriculture that has not only exacerbated the crisis leading to an environmental catastrophe but also destroyed millions of rural livelihoods. The biggest tragedy being that both the States had turned into a national capital of shame for farmers' distress, visible more through the increasing rate of suicides in the rural areas. Making available cheap credit to these marginal farming communities, as has been announced, will not be helpful. What these poor and marginalised need immediately is income support (Prabhakara Rao in the words of Devinder Sharma, Personal Communication 2008). This fight continues. On the INSAM website you can find several desperate messages of a group called the "Forum for Tropical Water", which is led by Mohan Reddy Vishwavaram from Hyderabad. On 12 July 2009 they stated "The modern farm system is resource killing and more so climate killing. It is suicidal. We hold it that the farmers' suicides are climate deaths sourced to the Green Revolution (GR) inspired crash of the hydel (=hydrological) greenhouse. The oft-repeated crash of millions of farm based livelihoods are once again sourced to the GR inspired climate change. Millions of farm households are turned into climate refugees. The modern farm system is thus suicidal" (Vishwavaram 2009).

It must in my view be realized that agricultural meteorology in developing countries should be applied against such backgrounds and discussions on resources entitlements (e.g. Dietz 1996) (see for example also Chaps. IV.1, IV.2, IV.5 and IV.9). This book wants to bring building stones for an educational revival and renewal in the fields of application in agrometeorology, that also refocus many directions of research into people oriented undertakings. The livelihood crises of farmers and the serious problems of their agricultural production environment should be the focus everywhere. We are assisted in our aims by the fact that climate change and economic crisis related developments have exacerbated these livelihood crises and by the developments reported in the previous parts of this book. Where possible we focus again on case studies.

There is still much experience to be exchanged beyond what we have now collected as basic practical material in the recently rewritten Guide to Agricultural Meteorological Practices (GAMP) for which I happened to be the leader of the WMO/CAgM Expert Team for the writing of its third edition (WMO 2010). The third part of this book should therefore become complementary to the GAMP and give background agrometeorology for which there was no place in the limited space of the Guide, following the various fields of application in agrometeorology and neighbouring disciplines, but in the spirit designed above.

Because we have separated the basic sciences completely from the applied sciences in the present book, it is differently organized compared to the GAMP, with its remaining roots in the support systems, its historical past and its meandering emphasis on trendy subjects. These are all very acceptable for such a publication but not for a book like ours. In our context, matters of action support systems, of policy support options and of capacity building policies should also get more attention than in the introductory chapter of the GAMP (Stigter et al. 2010). Opportunities for designing and establishing agrometeorological services should be the guiding principle in dealing with these interdisciplinary applications.

For each of these fields the review of operational agrometeorological knowledge should include agrometeorological aspects of how to cope operationally with risks and uncertainties from and preparedness for (i) extreme events and their consequences caused by meteorological and climatological disasters on all time scales, including related aversion/evasion attempts; (ii) pests and diseases, including countervailing measures; (iii) trying to use beneficial climate and weather and (iv) applications of agrometeorological services themselves, such as offered by agroclimatological characterization, design of microclimate management and manipulation, weather forecasting (including agrometeorological forecasting) and climate prediction, proposals of response farming, crop insurance and other advisories prepared for and by farmers in the previous three aspects.

As explained in Part I, the approaches of the Chaps. III.2, III.3, III.4, III.5 and III.6 have been inspired by the Contents of Annex I.I of Part I, and the first four have all sub-chapters on (1) Strategic use of climate information, (2) Coping with climate variability and climate change, (3) Coping with extreme meteorological events, (4) Tactical decision making based on weather information, and (5) Developing risk management strategies. One can recognize in the similar titles of the various sections of these sub-chapters the approaches of the contents of the syllabus proposals in Annex I.1. See the details in Sect. 1.4.1. We hope that the contents, with many case studies, will assist in developing curricula in applied agrometeorology in these directions and in designing research that is of use in solving the livelihood crises of farmers, through agrometeorological services. This will again support such curricula with new case studies.

In Chap. III.2 the general perspective is *monocropping in the Open* and the available agrometeorological literature is most abundant because it is the more general form of agricultural production in the western world, and the more advanced production in other parts of the world, for which most research has been done. One may argue that this is particularly a form of industrialized agricultural production with commercial purposes. It does need little introduction because everybody is very familiar with this subject.

Das (Personal Communication 2007) argued that monocultures are cultivated communities that consist of only one species. The land is often flat and readily amenable to mechanization, which is used at all stages of crop production. Agroecosystems are dynamic, being subjected to change from intervention by farmers and changes in weather factors. Monocultures may experience intraspecific competition. Competition arises because the supply of resources at a production site is less than the collective ability of use by closely spaced plants. Plant competition sometimes has casualties. Where plant spacing is close (high density), as occurs in the seeding of grasses and forage legumes, smaller plants become crowded out of community. This competition-induced mortality is called self-thinning.

This phenomenon is useful in nature but undesirable in crop production since it wastes soil nutrients; plants use some of it, only to die eventually. The production activity under monoculture is susceptible to pests and disaster. Pest outbreak can wipe out the entire enterprise since all plants are equally vulnerable to a particular pest. Crowding response in plants under monoculture, which is manifested through change in the crop environment and weather conditions favorable for occurrences of pests and diseases, needs to be considered in any decision making for agricultural management (Das, Personal Communication 2007).

Luigi Mariani and Osvaldo Failla (Personal Communication 2009) state that a correct perception of risk by farmers, extension services and agricultural authorities is quite important. The right perception is strictly related to the concept of probability, which in meteo-climatology is strictly linked to the two following concepts:

- the idea that the quantitative information about climate must be expressed with a particular emphasis to probabilistic aspects (for example a statistical approach with suitable techniques is necessary not only for average values but also for extremes);
- the idea that the use of forecast products must be based on the presupposition that they are the expression of a probability of future events (as wrote many years ago Sutton in a revealing textbook of meteorology).

Today, an Italian newspaper creates a controversy for a wrong prediction for the Easter holydays; this means that there is a cultural gap still to be overcome (Luigi Mariani and Osvaldo Failla, Personal Communication 2009).

In some personal communication (2009, with the references by him), Allen Riebau indicated that the United Nations Framework Convention on Climate Change (UNFCCC) uses the term “climate variability” for non-human caused climate variations (IPCC 2001a,b). The term “climate variability” is also used to denote deviations of climate statistics over a given period of time (such as a specific month, season or year) from the long-term climate statistics relating to the corresponding calendar period. In this sense, climate variability is measured by those deviations, which are usually termed anomalies (NSIDC 2009). Such variations can be at regional or continental or perhaps even global scales and usually last a decade or less.

As society has become aware of the potential of increased concentrations of green house gases to change climate, questions are being asked as to whether or not a spate of recent natural disasters can be associated with climate change and variation attributable to human activities. There is a cautious consensus building that the answer to these questions is yes. One must be careful, however. Climate variability is natural. In fact, climate change detection is difficult due to the natural variability of the climate system. The idea that climate variation itself can be increased, perhaps a most fundamentally significant part of anthropogenically induced climate change, is disconcerting precisely because climate variations have often engendered natural disasters (Allen Riebau, Personal Communication 2009).

The consensus that climate variability can be influenced by changing the dynamics of the atmosphere and oceans through human-caused green house gas emissions has resulted in predictions about what changes may be ahead. The number of occurrences of extreme variations is predicted to increase and their magnitude, the extremes of such episodes of change, will also potentially increase. Consequently, the occurrence of natural disasters will also increase. If such is true, the potential for world-wide economic and social disruption is enormous (NOAA 2007) (Allen Riebau, Personal Communication 2009). The above considerations are not only important to Sect. III.2, but also to the other parts of Part III.

Chapter III.3 deals with the same sub-sections but for *multiple cropping*, which means growing more than one crop on the same piece of land during one year (Stigter and Baldy 1989). If "during one year" is replaced by "at the same time" it is also called *polyculture*, in which emphasis is often on the ecological framework but the term *multiple cropping* may be wrongly interpreted (e.g. Geno and Geno 2001). There is only one textbook (in two languages) on agrometeorology of multiple cropping (Baldy and Stigter 1993, 1997), which itself is proof of the neglect of the tropics and other warm climates in applied agrometeorology. We therefore give some particular attention here to the definitions involved (Stigter and Baldy 1989).

Multiple cropping is a traditional method of intensive farming in warm climates attempting optimal use, also with respect to risks of total crop failure in dry farming, of (associations of) local or other varieties of food and cash crops (including trees) proven to be suitable. This way there ideally should also be optimal use of land, water, solar radiation and other climatic factors, nutrients, labour and other socio-economic factors such as those related to round the year food availability for the farmer's household, marketability and prices.

It is least confusing to distinguish in the terminology (i) *mixed (inter)cropping*, as growing more than one crop on the same piece of land at the same time; (ii) *relay (inter)cropping*, as planting crops between plants or rows of an already established crop during the growing period of (a) first planted crop(s) or more specifically growing two or more crops simultaneously during part of the life cycle of each; and (iii) *sequential cropping* as growing more than one crop in the same piece of land but during a different part of the year, called *double cropping* by others (e.g. Brown 2003).

In the context of these definitions, *row and strip (inter)cropping* are mixed (inter)cropping in fixed patterns. *Agroforestry* is a form of mixed cropping, including intercropping in early tree phases and alley cropping, or a form of relay cropping after establishment phases of trees, but only in the first definition of relay cropping, with trees/bushes as one or more of the crops (Stigter and Baldy 1989). One may call the latter heterogeneous intercrops and those of different (varieties of) cereals or cereals and pulses etc. homogeneous ones (Baldy 1986), but reality is more complex than simple nomenclature may be able to cover (examples in Stigter and Baldy 1989).

More important from the point of view of agrometeorology is the question whether higher yields in a mixed, inter- or relay cropping system are due to a more complete use of the available resources over time or a more efficient use of the same resources in space. Because of sustainability in fragile or vulnerable systems, special attention is needed for responses in cases of actual limiting factors and of advantageous factors (services rendered) of one crop to the other (e.g. Stigter and Baldy 1993).

Stigter and Baldy (1989) distinguished and exemplified four types of multiple cropping systems with an ultimate distinction in the management of their biomass and the reasons behind this management. This will remain clear in the various examples of Sect. III.3. Multiple cropping of the first type is the purely sequential system in the same crop space or part of it. The second type are spatial and temporal intercropping systems without "active" services rendered from any intercrop to another crop. There are "passive" services on resource use in time and space. In the third type there are "active" services resulting in microclimatological (Stigter and Baldy 1991; Stigter 1993) and/or other advantages, for a sequential crop (carrying over effects) or a companion crop and/or the cropping environment. The fourth type are complex combinations of dominating and dominated components in space and time of highest intimacy (oases, homegardens).

Climate information and technology can be used to guide in the practice of multiple cropping (e.g. Andrews and Kassam 1976). Ofori and Kyei-Baffour (Personal Communication 2009) argue that the same can be said of climate knowledge and technology to increase the profitability and sustainability of multiple cropping. Examples of climate based decisions are choices of cultivar. Cultivars must be ranked and selected according to water use, demand for soil nutrients (e.g. nitrogen and phosphorus) light use, plant rooting characteristics and compatibility under crop rotation. Other examples of climate based decisions are selection of crop mixtures. For example, climate conditions under which relay cropping can be done will not be the same for double cropping. It all depends on the number of days in the year during which crop growth can be possible for a given location. In taking production decisions several questions can arise. Among these are: Is the growing season long enough to accommodate selected species in a two crop annual system? What form of resource protection is of interest? Is it to increase household food needs? Is it to increase soil fertility?

Ofori and Kyei-Baffour (Personal Communication 2009) also argue that the first step is to determine the farm planning goals which include the household food security, income generation needs, livestock feed requirements, labor and coping skills and farm power and labor availability. The second step is to go through the factors that limit crop productivity in the area. These include water, solar radiation, and length of the growing season, soil fertility, topographical condition, soil erosion, flood, landslides, pests and diseases, cultivation period, soil temperature, air temperature, ground surface conditions, climate patterns. Select crops that grow under the prevailing local environmental (climatic, topographical) conditions bearing in mind the farmers' needs and sufficient protection of the natural resource base. What techniques can be used to grow the selected crops so that farmers' welfare will be increased, the natural resource base is protected and optimal resource use is achieved?

In one of his Boxes in Chap. III.4 on *Applied Forest (Agro)meteorology* Allen Riebau writes that, while reasoning and objectivity as hallmarks of the scientific method are pivotal, science has increasingly been held to account for issues that are technological, social, and ethical. This is certainly true for forest managers and forest meteorologists. Some factors for evaluating science as applied to tactical decision making are that it should be technologically usable (for example not so advanced as not being able to be applied due to technological limitations), acceptable socially, and ethical. Social acceptance and ethical discussions may at first sound far afield for practical matters such as forest meteorology. However, tactical and operational activities for forest fires and floods are examples of how controversial social and ethical considerations even for the most transparently beneficial endeavours can be (Box III.4.4 in Sect. III.4.1.(c)). See also Chap. IV.2.

The growth cycle of forests usually covers a period that can span several decades. The impacts of year-to-year and decade to decade climatic variability are integrated over the period. The strategic use of climatic information in forestry planning, management and operations is important in addressing the issues related to climatic variability and potential climate change (Dick Felch, Personal Communication 2009).

In a closed canopy one can not grow agricultural crops, but between scattered trees one can, because of differences in microclimate. This is also why crops are grown together with young forest trees but no longer when they get older (e.g. Baldy and Stigter 1997). Forest microclimates differing from the bulk forest climate can only be found at forest edges and in clearings or natural openings in the forest, that have therefore got special attention in the forest (micro)climate literature (e.g. Geiger et al. 1995). This Chap. III.4 has of course several aspects. First there is weather and climate influence of and on the closed canopy forests, then there is some attention for agricultural undertakings, including livestock, in and around forests. There is more of the former than the latter because non-forest trees have their own Chap. III.5.

In Box III.4.5 in Sect. III.4.1.(d) it is argued that much more than half the forests that not so long ago covered the earth are gone and deforestation is expanding and accelerating. The health and the quality of remaining forests are declining. However, our relationship to forests has evolved in some positive ways as well. In some places there has been a shift from unrestrained boom-and-bust forest exploitation and conversion to more sustainable forest management for a wider range of goods and services. People who have lived in and near the forest for generations are being recognized as forest managers in many places, not forest destroyers. New ways of satisfying the need for forest products less wastefully are also being pursued. Management for timber commodities and conversion of forests to other uses has reduced or curtailed the ability of forests to provide many other benefits and services. These include producing non-timber materials such as food, fodder, fish and medicines; purifying and regulating water supplies; absorbing and decomposing wastes; cycling nutrients; creating and maintaining soils; providing pollination, pest control, habitat and refuge; regulating disturbances; and regulating local and global climates (Abramovitz 1998). These are the subjects related to our approaches in applied agrometeorology of this Chap. III.4.

Human activities such as tree cutting have altered species composition and modified forest structure to such an extent that large stretches of forest have been replaced by woodland or shrub land. When forest degradation is described as a process in which basal area and canopy closure are ultimately reduced, in spite of regrowth, one must conclude that degradation as a result of tree cutting is a widespread phenomenon (Smiet 1992). Burning forests to clear land for farming releases about a fifth of all the greenhouse gases. Paying landowners to let forests grow is promoted by the United Nations as a viable way to fight global warming, but experts first have to puzzle out how to insure trees. The UN's focus so far is on protecting tropical forests. But owners of forests from Siberia to Scandinavia are interested in carbon credits. Under UN plans, owners will get carbon credits to slow the destruction of tropical forests. So carbon sequestration has become part of forest (agro)meteorology as well.

Trees and forests have evolved numerous times in the history of the earth, suggesting a repeated trend to generate rich self-watering terrestrial habitats. There is scope for self-stabilizing interactions to arise. We need to unravel the feedback processes and thresholds that operate spatially at different scales, and the influences that act upon them. Acceptance of the biotic pump discussed in Box III.4.2 of Sect. III.4.1.(b), would add to the values that society places on forest cover. By raising regional concerns about water, acceptance of the biotic pump demands attention from diverse local actors, including many who may otherwise care little for maintaining forest cover.

The Chap. III.5 is on the *Applied Agrometeorology of Non-forest Trees*, certainly for the first time that this subject is so extensively dealt with on an equal footing with forest (agro)meteorology, monocropping and multiple cropping, to which one may argue that it also belongs, when we want to talk about "tree crops" that do not grow alone. Where non-forest trees do grow without associated crops (including grasses) or livestock, they may have protective and/or productive or ornamental functions. As "trees outside forests", they present a key factor in integrated urban and rural management. What follows below as background comes from Bellefontaine et al. (2002).

Rural people around the world are of one mind when it comes to the durability, availability and use of the goods and services provided by tree resources, whether inside or outside the forest. These men and women make no distinction between field trees and forest resources, perceiving the clear and close link between the two, and their interaction. Policy makers and planners, however, tend to view these resources as different entities. It seems clear that "trees outside forests" have not yet succeeded in arousing real interest at the top. So there is a need to describe and comprehend the dynamics of trees and shrubs on rural and urban land, and their interaction with forest dynamics.

This should lead to a better understanding of off-forest tree management and towards integrated and sustainable management of natural resources and of forest, farm, pastoral and urban land. Trees outside forests may come under either farm legislation or forestry legislation, or a combination of the two, or be totally ignored by either or both. National laws and regulations covering trees can be contradictory. Forest policies and the official services responsible for the management of wood resources often extend their prerogatives to all trees, even those growing on agricultural lands. Rules governing land tenure as well as customary or formal access to resources are all grafted onto these legal texts and policies.

Trees outside forests, as a fundamentally multipurpose resource, are more intimately linked to the society around them than forest trees. Their productive, ecological and cultural functions are incisive, and their social, economic and environmental roles help to sustain households and household income. They are instrumental in national and international economies. They promote the conservation and sustainability of tree resources. A review of their role in peasant income acquisition strategies and potential value as economic and market indicators constitutes a challenge and innovation in the approach to forestry. The important uses and services of "trees outside forests" are known and valued but the global facts and figures on tree cover, wood production and wood products for this resource still need to be quantified and assessed in economic terms.

What indications we do have come from local or national assessments. In Sri Lanka, for example, 73% of the wood and 80% of the fuelwood is derived from homegardens and trees growing on farmland. In China, 1.8 billion eucalypts have been planted on farmland, but 0.95 billion on industrial plantations. In Vietnam and Thailand, 15 times as many trees grow in fields as in plantations. It is accordingly not a simple task to tease out the dynamics of "trees outside forests". Combining data on forest dynamics with the dynamics of trees growing on agricultural and urban land should give new insight into world trends for wood resources, confirming locally observed trends for shrinking or expanding tree cover.

There is a close and constant link between people and the changing pattern of "trees outside forests", which have been selected, maintained and protected in accordance with usages and needs that are as much cultural as material. Human practice reflects "a paradoxical complexity which makes the clearer of land into the guardian of the tree and the agent of tree development, and much more than simply one more factor in an implacable ecological dynamics". Tree management practices differ in peasant societies and pastoral societies, and between men and women. They are the outcome of local and traditional technical skills which people have fine-tuned over time in answer to the random winds of ecological change, economic change and political change. Paying attention to the lore accumulated by human societies means gaining some sense of how people see their natural resources, and how these resources foster social and symbolic meaningfulness within a given society.

Local and traditional environmental management skills are not receiving due consideration as beneficial lore which could be usefully tapped. Economic constraints, on the other hand, do constitute a means of measuring sustainable natural resource management in general, and tree resource management in particular. It is common now to see poverty quite naturally lumped together with resource overexploitation and resource abuse. It would be a good idea, however, to spell out the practices of the various components of the market economy, which have by now penetrated even the most remote corners. They are much more responsible for the new forms of resource exploitation. The impact on ecological equilibria can be catastrophic for people who were formerly quite capable of sustainably subsisting off these same resources. Unquestionably, one major stage in the promotion of "trees outside forests" is to reach a sufficiently broad agreement on the definition of these resources and ensure acknowledgement of their social, economic and ecological contributions. The next stages are to encourage the formulation of policies incorporating the international environmental targets, devise strategies better attuned to the current trend toward decentralized decision-making, and measures that reflect stakeholder interests and economic exigencies.

The status, functions and future of off-forest trees raise a complex set of questions in the various production systems where they grow. Three examples illustrate this complexity. The first concerns agroforestry in the humid tropics in Africa, a region still not definitively classified as either forest or farmland. The second covers upland coffee-growing areas in tropical Mexico and Central America. These plantations are trying to reconcile economic and ecological imperatives. And the last deals with line-planting systems, where protection and management are one component of a broader system of integrated land use management. Throughout the world (and most of history), peasant farmers have wandered, exploited and worked the forests, often refashioning them to suit their own needs. Ecosystems repeatedly subjected to human activity become heavily modified in their composition, structure and functions, sometimes losing a large portion of their tree cover. Some systems, such as the Indonesian agroforests, lean more toward the forest component, but they are nonetheless the outcome of extreme human ecosystem intervention in which farmers tended to singly and collectively appropriate the land and its resources.

Historically, policy makers and donors have concentrated almost exclusively on forests and wood production in policy terms, documenting the goods and services offered by trees and forests. More recently, non-wood forest products, like the social and environmental services of trees, have attracted greater interest. What is now needed, particularly in light of these trends, is greater consideration for "trees outside forests". Developing and developed countries alike now acknowledge the decisive cultural, environmental and productive role of these resources. The category of "trees outside forests" covers a wealth of tree systems supplying a vast and varied range of products and services. In the countryside, trees give wood and fruit, helping to maintain soil fertility. It is against the above background (from Bellefontaine et al. 2002) that this Chap. III.5 has been composed, using the term “agroforestry” or “non-forest trees” depending on the subject covered.

In Chap. III.6 we are dealing with *Applied Agrometeorology of Other Forms of Agricultural Production*, where we first handle Animal husbandry, then Crops under cover, the first one more widely than the second. Finally we have single papers on Fisheries, Urban agriculture and Precision farming.

In the original planning of the book, we had in mind the same kind of chapters as discussed above for Animal husbandry, Crops under cover and Fisheries. Discussing this with experts from these fields, it only basically made sense for Animal husbandry.

For Crops under cover, the field had changed so much over time that we were advised not to try to deal with modern climate controlled glass houses, that are hardly considered to fall under “Applied Agrometeorology”. The technology involved is too specialized to be of interest to people outside that specific field. So we limited ourselves in Chap. III.6 to some agrometeorological aspects of simple plastic and glass greenhouses, but used Chap. IV.7 to deal with some physical aspects of such greenhouses as a case study in agricultural physics. This appeared sufficient to handle aspects of improved growth and selection processes of (changes in) covered cropping in simple green houses, coping with extreme meteorological events and combating disasters.

For Fisheries the outline of the sections did simply not apply and it was impossible to find sufficient new expertise in the agrometeorological aspects of fisheries after the recent Chapter in the new WMO Guide to Agricultural Meteorological Practices (Boyd and Pine 2010).

For Animal Husbandry, however, the situation was different because of the existence of the Sects. III.2.1.(e), III.3.1.(e) and III.4.1.(e), on “Selection of (changes in) livestock management patterns” for monocropping, multiple cropping and forestry related farming systems respectively. The kind of introductional story that we wrote above for the other subjects can be found there. Moreover, the Chap. III.3.1.(e) also deals with various other aspects regarding livestock issues. In discussion with the experts concerned we selected seven subjects that also occur in the four earlier Chapters as most relevant for dealing with applied agrometeorological aspects of “Animal husbandry”.

Although we indicated to authors that they would not count towards the word limits set for the Sections, Tables, Figures, Pictures are relatively rare in this Part III. Case studies have particularly been descriptive and quantitative studies other than simple ones are still relatively rare in on-farm participative studies in agrometeorology that must lead to agrometeorological services (see also Part II). Where such data do exist they are often not very useful as illustration and the final results from which we should learn are more usefully given descriptively. The Boxes prepared should therefore be seen as illustrations in this book.

References

Abramovitz JN (1998) Sustaining the world's forests. State of the world 1998. A Worldwatch Institute Report on Progress Towards a Sustainable Society. Norton & Co, New York/London, pp 21–40

Andrews DJ, Kassam AH (1976) The importance of multiple cropping in increasing world food supplies. In: Papendick RI, Sanchez A, Triplett GB (eds) Multiple cropping. ASA special Publication 27. American Society of Agronomy, Madison, pp 1–10

Baldy C (1986) Agrometeorologie et développement des regions arides et semi-arides. [Agrometeorology and development of arid and semi-arid regions.] INRA, Paris, 114pp

Baldy C, Stigter CJ (1993) Agrometeorologie des cultures multiples en regions chaudes. [Agrometeorology of multiple cropping in warm regions.] Collection "Du Labo au Terrain". [Series "From the Lab to the Field".] INRA, Paris (avec CTA, Ede), 246pp

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Bellefontaine R, Petit S, Pain-Orcet M, Deleporte P, Bertault J-C (2002). Trees outside forests. Towards better awareness. FAO Conservation Guides 35, Rome. http://www.fao.org/DOCREP/005/Y2328E/y2328e02.htm#TopOfPage

Boyd CE, Pine H (2010) Application of agrometeorology to aquaculture and fisheries. Chapter 13 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Brown LR (2003) Plan B: Rescuing a planet under stress and a civilization in trouble. W.W. Norton & Co., New York. http://www.earth-policy.org/Books/PB/PBch8_ss3.htm

Dietz T (1996) Entitlements to natural resources. Contours of political environmental geography. International Books, Utrecht, Netherlands, 80pp

Geiger R, Aron RH, Todhunter P (1995) The climate near the ground, 5th edn. Vieweg, Braunschweig, 528pp

Geno L, Geno B (2001) Polyculture production. Principles, benefits and risks of multiple cropping land management systems for Australia. RIRDC Publication No 01/34. http://www.rirdc.gov.au/reports/ORG/01-34sum.html

IPCC (2001a) Climate change 2001: the scientific basis. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds) A contribution of working Group I to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, 881pp

IPCC (2001b) Climate change 2001: impacts, adaptation, and vulnerability. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) A contribution of working Group II to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, 1032pp

NOAA (2007) Observing climate variability and change. http://www.oar.noaa.gov/climate/t_observing.html

NSIDC (2009) Arctic climatology and meteorology PRIMER for newcomers to the north. National Snow and Ice Data Centre (NSDIC). http://nsidc.org/arcticmet/

Smiet AC (1992) Forest ecology on Java: human impact and vegetation of montane forest. J Trop Ecol 8:129–152

Stigter CJ (1993) Research on microclimate management and manipulation in multiple cropping: its contribution to agricultural production meteorology in tropical climates. Invited paper, National Seminar on Agricultural Production and Protection Meteorology, CASAM, Pune, 24pp

Stigter CJ, Baldy C (1989) Agrometeorology of multiple cropping systems: biomass management and the low external input African farmer. Proceedings of the 2nd ICTP/SAPAM Workshop on the Applicability of Environmental Physics and Meteorology in Africa, Addis Ababa University, ICTP/SAPAM, Ethiopia, no page

Stigter CJ, Baldy C (1991) Microclimate and protection of the tropical agricultural environment. In: Wolf JN (ed) Influence of the climate on the production of tropical crops, IFS/CTA, Stockholm/Ede, Ouagadougou, Burkina Faso, pp 172–184

Stigter CJ, Baldy CM (1993) Manipulation of the microclimate by intercropping: making the best of services rendered. In: Sinoquet H, Cruz P (eds) Ecophysiology of tropical intercropping. INRA, Paris – Guadeloupe, pp 29–44

Stigter K, Baier W, Barrie I, Brunini O, Dommermuth H, Gat Z, Gommes R, Keane T, Chan Ah Kee, Lomas J, Milford J, Ravelo A, Rijks D, Samui RP, Walker S, Wang Shili, Weiss A (2010) General. Chapter 1 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Vishwavaram MR (2009) Restating our position on climate change: modern farm systems/green revolution induced climate change & global warming. Taken up on the INSAM website (www.agrometeorology.org) on the “Agromet Market Place” of 16 July.

WMO (2010) Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

III.2 Applied Agrometeorology of Monocropping in the Open

III.2.1 Strategic Use of Climate Information

III.2.1.(a) Combating Disasters: Monocropping

Kees Stigter

This is a short case study review of the strategic use of climate information in combating disasters in a development context (e.g. Glantz 1997; Südmeier-Rieux et al. 2006; Sacks and Rosenzweig 2007). Box III.2.1 reviews what we do in this book on this subject. We like Lassa's (2006) approach considering a disaster the forced marriage between a hazard and vulnerability. The purpose then is to increase with farmers as decision makers the awareness on potential climate and climate related hazards and their mitigation in general (e.g. FAO 2002) and for monocropping, including its dangers, in particular (e.g. Sanchez 2001; Huda and Packham 2004), with a strong wish to reduce vulnerability by preparedness (e.g. Rathore and Stigter 2007). Also Stigter et al. (2007) indicated that to cope with impact problems of frequently occurring disasters, both the vulnerability of people should be reduced and the hazards should be mitigated, which therefore means fighting on at least two different fronts. What is often badly understood by those that have to carry out policies of disaster impact reduction is that there is a long process involved in for example a drought or flood hazard to produce a disaster (e.g. Brandt et al. 2001; Connelly and Wilson 2001; Stigter et al. 2003).

The role of applied agrometeorological science in combating disasters in this context is to use the understanding that basic science has reached on the most important hazards endangering crop growth in a region as well as on possibilities for their mitigation, to have extension make these farmers aware of these hazards and their own vulnerability (e.g. Gathara et al. 2006). See also the enormous amount of scientific information with introductions on the agrometeorological contexts of the support systems of data, research, training/education/extension and policies available in this respect in WMO (2010), for which I was the Editor-in-Chief. However, also some traditional knowledge empirically reached such standards, as follows for example from protection against extreme events provided by the rebuilt Andean waru – waru monocropping systems (e.g. Altieri 1996; MOST/NUFFIC 2003) or the preserved drought and flood forecasting related to (among others) wet

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_7,

Box III.2.1

To illustrate once more how this book was built, further details on combating disasters for the different main fields of this Part III were collected for Sects. III.3.1.(a) on multiple cropping, III.4.1.(a) on forest (agro)meteorology; and III.5.1.(a) on (agro)forestry, III.6.A.(vi) on animal husbandry and III.6.B.(ii) on covered cropping systems. The same applies to Sect. III.2.3.(A) on problems and solutions in coping with extreme meteorological events in agricultural production, and challenges remaining for the use of science to contribute to problem analyses and designing valuable solutions in this context: monocropping; Sect. III.3.3.(A) on the same for multiple cropping; Sects. III.4.3.(A) and III.5.3.(A) on the same for forest (agro) meteorology and non-forest trees respectively. In Sub-Part III.6 also sections were written with details on the same for agrometeorology of animal husbandry (Sect. III.6.A.(i)), agrometeorology of cropping under cover (Sect. III.6.B.(i)) and agrometeorology of fisheries and aquaculture (Sect. III.6.C.(i)), completing this picture for a wide range of fields in agrometeorology.

rice growing in Sri Lanka (Upawansa 2003). This is also further discussed in Sect. III.3.2.(i) for the role that multiple cropping can play in this respect.

According to Smith (1975), frost (e.g. Snyder and Melo-Abreu 2005) and various forms of pollution (e.g. NASULGC and ESCOP 2001) are some examples of primary hazards, while soil erosion (e.g. Al-Amin et al. 2005; Okaba et al. 2007) as well as incidence and intensity of pests and diseases (e.g. Strand 2000; Stigter and Rathore 2008) are some examples of secondary hazards that may be strategically avoided or combated and their effects strategically mitigated. Extreme weather related to temperature (e.g. UNFCCC 2007), precipitation (including floods, see e.g. MOST/NUFFIC 2003; Stigter et al. 2003) or the lack of it (e.g. De Pauw et al. 2000) and wind (including cyclones and other storms, see Sect. III.2.3.(A)) are examples of unavoidable hazards, the effects of which can only partly be mitigated in monocropping as well as in general (e.g. Rathore and Stigter 2007).

References

Al-Amin NKN, Stigter K(CJ), Elagab MAM, Hussein MB (2005) Combating desert encroachment by guiding people, wind and sand. J Agric Meteorol (Jpn) 60:349–352

Altieri M (1996) Indigenous knowledge re-valued in Andean agriculture. ILEIA Newsl 12(1):7–8

Brandt SA, Spring A, Hiebsch C, McCabe JT, Tabogie E, Diro M, Wolde-Michael G, Yntiso G, Shigeta M, Tesfaye S (2001) The “tree against hunger”: Enset-based agricultural systems in Ethiopia, http://www.aaas.org/international/ssa/enset

Connelly S, Wilson N (2001) Trees for semi-nomadic farmers: a key to resilience. LEISA Mag 17(1):10–11

De Pauw E, Göbel W, Adam H (2000) Agrometeorological aspects of agriculture and forestry in the arid zones. Agric For Meteorol 103:43–58

FAO (2002) New challenges to the achievement of the World Food Summit goals, http://www.fao.org/DOCREP/004/Y1780E/y1780e04.htm

Gathara ST, Gringof LG, Mersha E, Sinha Ray KC, Spasov P (2006). Impacts of desertification and drought and other extreme meteorological events. CAgM Report 101, WMO/TD 1343, Geneva, 85pp

Glantz MH (1997) Summary: ENSO/Famine early warning systems, discussions. In: Using science against famine: food security, famine early warning, and El Niño, http://www.brad.ac.uk/research/ijas/ijasno2/ijasno2.html

Huda AKS, Packham RG (2004) Using seasonal climate forecasting in agriculture: a participatory decision-making approach. ACIAR Technical Reports 59, http://www.aciar.gov.au/web.nsf/att/ACIA-6SGW3J/$file/TR59.pdf

Lassa J (2006) New direction needed for coping with disasters. Jakarta Post (Indonesia), January 16, p 6

MOST/NUFFIC (2003) Waru-Waru, a cultivation and irrigation system used in flood-prone areas of the Altiplano. Best practices on indigenous knowledge Peru BP-II.19, http://www.unesco.org/most/bpik19-2.htm

NASULGC, ESCOP (2001) A science roadmap for agriculture. Task force on building a science roadmap for agriculture, www.nasulgc.org/comm_food.htm

Okaba BO, Tenge AJ, Sterk G, Stroosnijder L (2007) Participatory soil and water conservation planning using an erosion mapping tool in the central highlands of Kenya. Land Degrad Dev 18:303–319

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties-regional perspectives: Asia. In: Sivakumar M.V.K. and Motha R. (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 53–69

Sacks L, Rosenzweig C (2007) Climate change and food security. Climate Institute, Washington, http://www.climate.org

Sanchez PA (2001) Tropical soils, climate and agriculture: an ecological divide? Harvard Conference on Raising Agricultural Productivity in the Tropics: Biophysical Challenges for Technology and Policy. http://www.worldfoodprize.org/assets/symposium/2001/transcripts/Sanchezpaper.pdf

Smith LP (1975) Methods in agricultural meteorology. Elsevier, Amsterdam, 210pp

Snyder RL, Melo-Abreu JP (2005) Frost protection: fundamentals, practice and economics, Vol. 1. Food and Agriculture Organization, Rome, 223pp

Stigter K, Rathore LS (2008) How to organize coping with crop disease risks of farmers in poor countries. Paper Presented at an Asian Pacific Network (APN) Finalizing Workshop of the Project "Climate and Crop Disease Risk Management: An International Initiative in the Asia-Pacific Region" in Dhaka, Bangladesh, 10 till 14 February. Available on the INSAM web site www.agrometeorology.org under "Needs for agrometeorological solutions to farming problems"

Stigter CJ, Das HP, Murthy VRK (2003) Beyond climate forecasting of flood disasters. Fifth Regional Training Course on Flood Risk Management (FRM-5), ADPC, Beijing, http://www.agrometeorology.org/index.php?id=273

Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi YM (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York etc, pp 171–190

Strand JF (2000) Some agrometeorological aspects of pest and disease management for the 21st century. Agric For Meteorol 103:73–82

Südmeier-Rieux K, Masundire H, Rizvi A, Rietbergen R (eds) (2006) Ecosystems, livelihoods and disasters. An integrated approach to disaster risk management. IUCN, Gland, Switzerland, app.iucn.org/dbtw-wpd/edocs/CEM-004.pdf

UNFCCC (2007) Relevant programmes, activities and views on the issues relating to climate related risks and extreme events. SBSTA. Twenty-sixth session, Bonn, http://unfccc.int/resource/docs/2007/sbsta/eng/misc05.pdf

Upawansa GK (2003) Ancient farming and modern science. Compas Mag 9:35–37, http://www.compasnet.org/english/dloadz/nl6/eco35-37.PDF

WMO (2010) Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

III.2.1.(b) Selection Processes of (Changes in) Land Use and Cropping Patterns: Monocropping

M.H. Ali and M.S.U. Talukder

Weather is one of the main sources of uncertainty and risk in many agricultural systems (for climate see Box III.2.2). Common weather phenomena on the earth include wind, rain, snow, fog; and less common phenomena include storms or tropical cyclones, heat and cold waves. Almost all familiar phenomena occur in the troposphere.

Box III.2.2 (Contributed by Nguyen Van Viet)

Viet reported in Stigter et al. (2007) that from an analytical point of view, floods, droughts, typhoons, frosts have been regionally recognized and economically studied as disasters to agriculture in Vietnam. Solutions have been sought in changing cropping calendars and patterns which are provincially and regionally proposed, and in proposals on water and tree management. This has resulted in government planning and designs and a systematic approach to improve this in the short run and as a long term strategy. Especially sowing times for the ongoing season in the Central highlands and the Mekong delta as well as some permanent changes in cropping patterns with two to three rice crops annually, that replace rice one time for a rotation with maize, sweet potatoes, cassava have been successful.

Farmers forced to migrate due to dam building successfully used designs developed as agrometeorological services for the agroclimatologically most suitable production systems. Also for example the design of water erosion prevention on sloping land by forage grasses and other permanent vegetation and of the stabilization of terrace banks and edges by grass strips have been successfully developed services for the hill farmers in Bavi District, Hatay Province.

M.H. Ali (✉)
Bangladesh Institute of Nuclear Agriculture, Mymensingh, Bangladesh
e-mail: hossain.ali.bina@gmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_8,

As to selection (of changes) of cropping patterns and land use for coping with extreme climatological events (ECEs), three much wider series of issues play in Vietnam but also more generally:

– *strengthen capability of climate forecasts on ECE and warning systems*. One of the short-term mitigation measures is an efficient ECE warning system. Needs are: (i) accurate and detailed forecasts of dangerous conditions for sufficient time in advance; (ii) rapid and suitable distribution systems for the forecasts, advisories and warnings to all interested parties; (iii) prompt and effective utilization of warnings by the government and public and (iv) build a website to exchange and collect information in the region and globally on climate disasters and ECE.

– *response measures to minimize disaster damages caused by ECE phenomena*: (a) promulgate or complement necessary legal foundations. This is the background and action direction to strengthen the effectiveness of disaster management agencies; (b) consolidate the organization structure of Committees for Flood and Storm Control at all levels, raise capability in responding to impacts of ECEs; (c) give specific responsibilities to each sector and staff. Improve equipment and capability of standing agencies; (d) make assessments on situations of ECE phenomena; (e) assess response probabilities to disasters and effects of ECE; (f) build adequate plans and have effective measures in preparation; (g) prepare communication and information systems; (h) prepare basic supply systems in terms of means of transportation, forces and sources for emergency relief and (i) organize training, exercises, studies and workshops.

– *basic and long-term measures of concern and the need of implementation*: (1) implement afforestation programs and protect upstream forest; (2) manage and monitor upstream reservoirs, especially reservoirs to regulate flooding; (3) clear riverbeds and river mouths to facilitate flood drainage, upgrade irrigation works; (4) strengthen and manage dyke portions to make them important flood-protection lines, upgrade sea dyke systems and existing river mouths and newly build dyke lines; (5) ensure sustainable principles in exploiting water sources, take advantage of the complex of water sources, especially underground water; (6) appropriately change the crop structure, especially plan specific trees in areas vulnerable to extreme weather; (7) exploit potential of unused land, in Vietnam especially in hills in the northern center and (8) prepare and strengthen capability of preventing some infectious diseases, protect community health.

The intensity, duration and frequency of rain cause flood and drought in an area. The disruptions of the ocean-atmosphere system (El Niño and La Niña) in the tropical Pacific have important consequences for weather around the globe. The most common weather phenomena that affect monocrops in an area are onset and length of the rainy season, prospects for dry spells and their lengths, storms, snowfall, and winds. If seasonal weather forecasts can be applied and integrated into the agricultural farm management system, it can increase preparedness and offer the potential to improve yields, and thus the livelihood of the farmers.

Many critical agricultural decisions of (changes in) land use and cropping patterns, ranging from farm to policy level, that interact with weather conditions must be made several months before impacts of weather materialize to either prepare for expected adverse conditions or to take advantages of favorable conditions. Hansen (2002) pointed out five prerequisites to achieve full benefits from climate forecasts in these selection processes, namely, (i) forecast information must address a need that is both real and perceived, (ii) benefit arises only through viable decision options that are sensitive to forecast information, (iii) benefit depends on prediction of the components of climate variability that are relevant to viable decisions, (iv) appropriate forecast use requires effective communication of relevant information, and finally (v) sustained use requires institutional commitment and favorable policies.

In "haor" (low-land, monocropping) areas of Bangladesh, farmers need the forecast 5 months prior to the phenomena, to select the appropriate crop variety (short or long duration). The farmers usually transplant rice in the months of December or January, and are concerned of the crop damage due to early monsoon rainfall (beginning at early April, causing flooding & damage of the crop). If there is a high chance of rainfall in April, farmers could consider early planting and select early maturing (short duration) crop varieties, but at the cost of sacrificing potential yield. In contrast, for a high chance of "dry spell" up to May (late monsoon), they might choose long duration crop varieties, which produce higher yields. This decision would then require knowledge of the forecast by the end of November. For upland crops, knowledge of likely disruptions due to dry/wet weather at the sowing/harvest season can allow farmers and harvest operators to select better plans for sowing/harvesting strategies (Everingham et al. 2002; Ali et al. 2005).

Coping strategies for weather phenomena may be broadly classified as (i) preparedness and (ii) mitigation practices. Preparedness as a coping strategy means preparedness for what cannot be prevented. Mitigation practices as a coping strategy means preparedness for what can be prevented. Avoiding hazardous weather phenomena through monitoring and early warnings, production adaptation, preparation for an agricultural rehabilitation program after floods, flood hazard mapping for land use planning, etc. are the strategies of preparedness. Flood water detention, flood diversion attempts for agricultural purposes, etc. are the strategies of mitigating effects of high intensity rainfall (flood).

In case of heat and cold waves, using seasonal temperature forecasting, shifting planting date, changing variety, application of irrigation and fertilizers, intercropping, growing off-season crops and choosing resistant varieties (together with microclimate management and agronomic manipulation), or a combination, to ensure that the temperature sensitive stage (e.g. flowering in case of cereal) can be avoided or tolerated to a certain degree, are the farm level preparedness and mitigation selections. For tropical storms, planting trees (implementation of afforestation, creating shelterbelts, Onyewotu et al. 1998) and selection of crop cultivars having strength to stand against strong wind, drilling depth, sowing date, seed rate etc. are the farm level preparedness and mitigation selections.

In many regions of the world, agricultural decision makers are incorporating climate forecasts into their decisions on land use and cropping patterns (see also Box III.2.2). For example, potato farmers in Florida saved their 1997 winter crop by contouring their fields and clearing state-owned drainage canals in anticipation of excess rain associated with El Nino (Jagtap et al. 2002). An Africa-wide agricultural input supplier markets seeds of cultivars based on their appropriateness to seasonal rainfall forecasts, and uses forecasts in planning their distribution among regions (Malusalila 2000).

Periodic regional climate outlook fora in Africa and Latin America bring forecast providers and stakeholders together regularly to develop consensus forecasts and explore opportunities for their use (Buizer et al. 2000). Agricultural support institutions in Australia, Zimbabwe and the southeast USA have incorporated seasonal climate forecasts into their operational programs for advising farmers. Hammer et al. (1996) analyzed the value of seasonal climate forecasting in deciding nitrogen application rates and cultivar selection in wheat cropping. They found that tactical adjustment of nitrogen fertilizer and cultivar could increase profit by up to 20%, and/or reduce risk by up to 35%.

Resource availability and policy issues (institutional) often determine the ability of agricultural decision makers to act on forecasts. Market policy and infrastructure strongly influence the range of economically viable options available to decision makers by controlling commodity prices, production input costs and transaction or marketing cost (Eakin 2000; Mjelde et al. 1996).

The recent view of researchers is that coping with weather phenomena requires holistic solutions derived from integrated, interdisciplinary, and participatory systems approach (Everingham et al. 2002; Meinke and Stone 2005; Meinke et al. 2006). Recently, discussion support software has been developed as a key vehicle for facilitating infusion of forecasting capability into practice (Nelson et al. 2002). The authors noted that the software is largely demand-driven and can compliment participatory action research programs by providing cost-effective general delivery of simulation-aided discussions about relevant management actions.

Climatic phenomena or climate variability relevant to agricultural management occurs at a range of frequencies or time scales, ranging from intra-seasonal, inter-seasonal, decadal, multi-decadal (Talukder 1987; Donald et al. 2004; Meinke and Stone 2005). The major challenge in coping with climatic phenomena is to further increase our understanding of causes and consequences of climate phenomena. Understanding the interactions between climate and agro-ecosystems, and the nature and timing of relevant climate-sensitive selection decisions, can clarify what forecast information is most relevant to the decision problem in a particular context (Hansen 2002). Challenges and complexities may also arise from prediction processes and from alternating decision option processes. The complexity of agro-ecosystem response to the range of combinations of management, initial soil conditions, climatic outcomes, and market outcomes – the "curse of dimensionality" – presents difficult methodological challenges for predicting impacts of selection options and management capability. The response of Vietnam is in Box III.2.2.

References

Ali MH, Amin MGM, Islam AKMR (2005) Probability analysis of monsoon and off-monsoon rainfall and crop planning in Bangladesh. Bangladesh J Environ Sci 11:290–295

Buizer JL, Foster J, Lund D (2002) Global impacts and regional actions: preparing for the 1997–98 El Nino. Bull Am Meteor Soc 8:2121–2139

Donald A, Meinke H, Power P, Wheel M, Ribbe J (2004) Forecasting with the Madden Julian Oscillation and the application for risk management. Proceedings of the 4th International Crop Science Congress, on the Theme "New Directions for a Diversified Planet" Held on 26 September–1 October 2004, Brisbane, Australia (Published in CDROM). Available at www.cropscience.org.au

Eakin H (2000) Smallholder maize production and climate risk: a case study from Mexico. Clim Change 45:19–36

Everingham YL, Muchow RC, Stone RC, Inman-Bamber NG, Singles A, Bezuidenhout CN (2002) Enhanced risk management and decision-making capabilities across the sugar industry value chain based on seasonal climate forecasts. Agric Syst 74:459–477

Hammer Gl, Holzworth DP, Stone R (1996) The value of skill in seasonal forecasting to wheat crop management in a region with a high climate variability. Aust J Agric Res 47:717–737

Hansen JW (2002) Realizing the potential benefits of climate prediction to agriculture: issues, approaches, challenges. Agric Syst 74:309–330

Jagtap SS, Jones JW, Hildebrand P, Letson D, O'Brien JJ, Podesta G, Zazueta F (2002) Responding to stakeholders demands for climate information: from research to practical application in Florida. Agric Syst 74:415–430

Malusalila PM (2000) Experiences of an agricultural input supplier. Proceedings of the International Forum on Climate Prediction, Agriculture and Development, IRI-CW/00/1, International Research Institute for Climate Prediction, Palisades, NY, pp 82–86

Meinke H, Stone R (2005) Seasonal and inter-annual climate forecasting: the new tool for increasing preparedness to climate variability and change in agricultural planning and operations. Clim Change 70:221–253

Meinke H, Nelson R, Kokic P, Stone R, Selvaraju R, Baethgen W (2006) Actionable climate knowledge: from analysis to synthesis. Clim Res 33:111–110

Mjelde JW, Thompson TN, Nixon CJ (1996) Government institutional effects on the value of seasonal climate forecasts. Am J Agric Econ 78:175–188

Nelson RA, Holzworth DP, Hammer GL, Hayman PT (2002) Infusing the use of seasonal climate forecasting into crop management practice in North East Australia using discussion support software. Agric Syst 74:393–414

Onyewotu LOZ, Stigter CJ, Oladipo EO, Owonubi JJ (1998) Yields of millet between shelterbelts in semi-arid northern Nigeria, with a traditional and a scientific method of determining sowing date, and a two levels of organic manuring. Neth J Agric Sci 46:53–64

Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi, YM (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha R (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 171–190

Talukder MSU (1987) Radiation and energy balances from standard meteorological observations in Bangladesh. J Inst Eng Bangladesh 15:17–22

III.2.1.(c) The Selection of Actual Preparedness Strategies for Dealing with Climate as Adopted in Monocropping

H.P. Das

Climate variability creates enormous problems with agricultural production and in natural resource management. Preparedness is needed. Climate forecast information could help farmers to stabilize yield through management of agroclimatic resources as well as other inputs (Gommes 1997). However, effectiveness of climate related preparations for enhanced agricultural production and protection can be improved through close collaboration among the relevant agencies and organizations, National Extension Services, National Agrometeorological Services and farming communities (Weiss et al. 2000). Although there may be other constraints before a forecast can be factored into decision-making, it is often these stakeholders that need additional information to offset risk as much as possible (Ziervogel and Downing 2004). Many farmers involved in participatory decision making processes have shown interest in using climate information and try to implement their own management practices. Farmers have built a strong knowledge base from practical experiences (Balasubramanian et al. 1998) gained over generations and this knowledge has to be valued for potential gain in farming. Stigter et al. (2005) stressed the use of traditional methods and indigenous technologies for coping with climate variability.

Crop production in industrialized societies is primarily monoculture. These monocultures are input-intensive, depending on agrochemicals (fertilizer and pesticides) for high productivity. Plants in this system feed at the same level in the soil and draw the same nutrients. Pests associated with the crop tend to build up with favorable climatic conditions, necessitating the intensive use of pesticides to manage them. Biomass accumulation in monocultures is exponential in pattern. This pattern is modified by plant density.

Hansen (2002) argued that agricultural decision makers would realize the potential benefits of climate information only if farmers are prepared for viable decision options. Effective forecast applications impose intensive demands on coping skills, as they are implemented through adjustments of possibly many interrelated

H.P. Das (✉)
Retired from Indian Meteorological Department, Pune, India
e-mail: hpd_ag@rediffmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_9,

decisions. Coping decisions that are realistic and adoptable by farmers need to be investigated for associated risks (Ingram et al. 2002). Ideally, to get optimal preparations, farmers and researchers exchange information, most often through intermediaries, that is useful for each other in a participatory co-learning approach to properly understand decision options through discussions supported by economic analyses.

Farmers in general, and specifically dry-land farmers, take cropping decisions mainly influenced by the input costs and perceived risks of economic loss, because of crop failures resulting from climate variability. Although farmers possess good understanding about their crops and give primary importance to economic returns, risk aversion is their boon to achieve higher production, even during a good rainfall season. Seasonal rainfall forecasts are required to take technical decisions on options like (a) choice of cropping system: single or double crop, (b) crop maturity type, (c) optimum plant population, (d) when to sow a first crop or a second crop, (e) decisions on application of fertilizers and their quantity and (f) taking into account the likely effect of seasonal climate on crop yields. The following paragraphs and boxes list some preparedness strategies for dealing with climatic variability as adopted in agricultural production. The specific examples come from India (Box III.2.3), Australia (Box III.2.4) and the USA (Box III.2.5).

Box III.2.3

In the Anantapur region of Andhra Pradesh, India, cost of seed is a large fraction of the cost of cultivation of rainfed groundnut, ranging from 20 to 35% depending on the seed rate used. Hence, it is important to determine the seed rate for the climate variability of the region. The seed rate used by the farmers is about half the recommended rate. On the basis of a survey of six districts around the Anantapur region, scientists have suggested that a major contributory factor to the low yield is lower plant density practised by the farmers (Singh and Nageswara Rao 2004). However, Singh's (1997) synthesis of field experiments at seven locations in different parts of India showed that increasing plant density from 15 to 30 per square meter generally increased average yields only between 3 and 10%. It is therefore necessary to determine the change in yield with change in plant density for the different types of rainfall patterns that occur over the region. It was found that in about 38% of the years, the yield at the higher plant density is higher by over 150 kg/ha^{-1}, which is about the level required to compensate for the additional cost of seed. Such an enhancement of yield with enhanced plant density only occurs for years with good rainfall and hence good levels of yield. Hence, only if skillful prediction of good rainfall years was possible, it appears appropriate to prepare for enhanced seed rate beyond what the farmers now use.

Box III.2.4

(I) In a case study in Australia, Carberry et al. (2000) demonstrated that using the SOI in preparedness contributed some skill to improving management decisions over a 2 year rotation. By changing cropping based on the Southern Oscillation Index (SOI) phase in the August–September period preceding the next two summers, average gross margin for the 2 year period increased by 14% over a standard fallow-cotton rotation, and cash flow improved in many years because an extra crop was sown. The SOI-based strategy did however increase the risk of economic loss from 5% of years for the standard fallow-cotton rotation to 9%, but this risk was considerably less than the 15% for sorghum-cotton and 19% for cotton-cotton rotations. (II) Also in Australia, particularly in the northern part of the grain belt, wheat is grown in an extremely variable climate. The wheat crop manager in this region is faced with complex preparedness decisions on choice of planting time, varietal development pattern and fertilizer strategy. A skillful seasonal forecast would provide an opportunity for the manager to tailor crop management decisions more appropriately to the season.

Hammer et al. (1996) examined the decisions on nitrogen (N) fertilizer and cultivar maturity using simulation analyses of specific production scenarios at a representative location (Goondiwindi) using long-term daily weather data. The average profit and risk of making a loss were calculated for the possible range of fixed (i.e. the same every year) and tactical (i.e. varying depending on seasonal forecast) strategies. Significant increase in profit (up to 20%) and/or reduction in risk (up to 35%) were associated with tactical adjustment of crop management of N fertilizer or cultivar maturity. Those years with SOI phase IV in January and February had decreased probability of late frosts. Consequently, in those years, chance of frost would be reduced for any given maturity type. Alternatively, in those years it would be possible to plant earlier maturity types (than those suggested by the fixed strategy) without an increase in chance of frost damage. The opposite occurred with SOI phase V years, as the probability of late frosts increased in those years. Hence, it would be necessary to plant later maturing types to avoid an increase in chance of frost damage. Tactical adjustment of cultivar maturity resulted in increased average profit and reduced risk of making a loss.

Box III.2.5

To illustrate preparations with the potential application of information about ENSO impacts on crops, Hansen et al. (2001) identified optimum management of maize and winter wheat in Georgia, USA, for a set of all years for each ENSO phase from 1923 to 1997. The management variables optimized included planting date, the amount of N applied at planting, and the amount and date of a second N application. The optimal strategies identified for wheat included later planting, less total N fertilizer, and a higher proportion of N applied at planting in La Nina years and earlier planting in El Nino years relative to all years. The optimal strategy for neutral years was similar to the strategy optimized for all years. Reduced precipitation during grain fill and enhanced rainfall near harvest (May) tend to reduce wheat yields, thereby reducing optimal N amounts. In contrast to wheat, the optimal strategy for maize following La Nina events included earlier planting. The optimal planting date for El Nino years fell between the optimal values for La Nina and neutral years, and matched the optimal values identified for all years. The earlier planting date for maize following La Nina events can be explained by enhanced precipitation from May to July, and reduced precipitation in August. The optimal planting dates result in tasseling in mid-June for the La Nina phase and early to mid-July for the other groups of years. Differences among ENSO phases in optimal N amounts were small for maize.

In high rainfall areas where there are a series of wet and dry spells, rainfall can be harvested in either farm ponds or in village tanks and can be recycled as lifesaving irrigation during a prolonged dry spell (Das 2003). The remaining water can also be used to provide irrigation for a second crop with a lower water requirement. However, no one strategy can be adopted universally (Das 2005). In fact, all such preparation strategies are location, time, crop, crop stage and (to some extent) socio-economic condition specific. Developing such strategies for each specific factor can help make agriculture sustainable.

There is need to have a Drought Watch System at district and state levels, which should be developed, implemented, and managed by experts in meteorology, agriculture, irrigation, public health, food supplies etc. (Das 2000). The pre-requisites for the operation of such a preparative drought watch system are:

(i) a network of rainfall stations, with reliable records of good quality, that are homogeneous and extend over a period of at least 20 and preferably more than 50 years;
(ii) weekly/monthly rainfall records that are in computer compatible form;
(iii) weekly/monthly rainfall totals that are available at the drought watch center within 2 or 3 days at the end of the week/month; and,
(iv) the drought watch centers should have the capability of issuing weekly/monthly drought watch statements whenever the rainfall situation demands.

In general, important information can be provided with a short time horizon for tactical applications concerning early warning (i.e. short cycle varieties, choice of alternative cultural systems, real time seed distribution, irrigation management etc.), and with a long time horizon for agro-economic planning with benefits at national and international scale.

References

Balasubramanian V, Ladha JK, Denning GL (eds) (1998) Resource management in rice systems: nutrients. Kluwer, Dordrecht, 355pp

Carberry P, Hammer G, Meinke H, Bange M (2000) The potential value of seasonal climate forecasting in managing cropping systems. In: Hammer GL, Nicholls N, Mitchell C (eds), Application of seasonal climate forecasting in agricultural and natural ecosystems. Kluwer, Dordrecht, pp 167–181

Das HP (2000) Monitoring the incidence of large scale droughts in India. In: Wilhite DA (ed) Drought: a global assessment, Vol. 1. Rauteldge, London/NewYork, pp 181–195

Das HP (2003) Agrometeorological aspects of drought and desertification. In: Agrometeorology related to extreme events. WMO 943, Geneva, pp 7–34

Das HP (2005) Agricultural drought mitigation and management of sustained agricultural development in India. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 277–303

Gommes R (1997) FAO's experience in provision of agrometeorological information to the user community. In: Sivakumar MVK, De US, Sinha Ray KC, Rajeevan M (eds) User requirements for agrometeorological services. India Meteorological Department, Pune, pp 53–77

Hammer GL, Holzworth DP, Stone R (1996) The value of the skill in seasonal climate forecasting to wheat crop management in a region with climatic variability. Aust J Agr Res 47:717–737

Hansen JW (2002) Realising the potential benefits of climate prediction to agriculture: Issues, approaches, challenges. Agr Syst 74:309–330

Hansen JW, Jones JW, Irmak A, Royce F (2001) El Nino-Southern Oscillation impacts on crop production in the Southern United States. In: Impacts of El Nino and climate variability on Agriculture. ASA Special publication 63, Madison, pp 55–76

Ingram KT, Roncoli MC, Kristen PH (2002) Opportunities and constrains for farmers of West Africa to use seasonal precipitation forecasts with Burkina Faso as a case study. Agr Syst 74:331–349

Singh P (1997) Impact of climate variability on groundnut. In: Manton M, Phelan A, Virji H (eds) Workshop on climate variability, agricultural productivity and food security in the Asian Monsoon region. Bogor, no pages

Singh P, Nageswara Rao V (2004) Crop models for crop management using seasonal climate forecasting. In: Singh KK, Raji Reddy D (eds) Proceeding of National Workshop on Seasonal Climate Prediction for Sustainable Agriculture, Hyderabad, 19–20 November, pp 39–51

Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005) Using traditional methods and indigenous technologies for coping with climate variability. Clim Change 70:255–271

Weiss A, Van Crowder L, Bernardi M (2000) Communicating agrometeorological information to farming communities. Agr For Meteorol 103:185–196

Ziervogel G, Downing TE (2004) Stakeholder networks: improving seasonal climate forecast. Clim Change 65:73–101

III.2.1.(d) More Efficient Use of Agricultural Inputs as Part of Adoption of Preparedness Strategies: Monocropping

Kulasekaran Ramesh

Desai (1988) indicated already 20 years ago that accelerated growth in agricultural production of developing countries depends on exploiting more fully the existing production potential and continuously raising that potential through technological change. He indicated that this requires sustained rapid growth in the use of inputs such as seeds of better quality, fertilizers, pesticides, farm implements, and machinery. Price policy issues at that time dominated in discussions on how to increase the use of these inputs, often without sufficient attention to certain non-price factors and policies. We now know that both price and non-price factors remain important. It must also be acknowledged that at present no achievements would have been in place, had millions of resource-poor farmers living mostly in the developing world not adopted new crops, varieties/hybrids, cropping systems and innovative production technologies. Thus, the secret of success lies in wide scale adoption of improved technologies by millions of small and marginal farmers (Paroda 2004).

Had there locally not been major agrarian reforms such as fixation of ceiling and consolidation of holdings, creation of infrastructure like roads, markets, major irrigation systems, production and ready availability of inputs like seeds, fertilizers, pesticides, availability of credit, fixation of minimum support price, buffer stocking of food grains, public distribution systems, food for work programs, etc. backed by agricultural research, education and extension systems, these achievements would have not been possible. Hence, these building blocks were the most critical for attaining agricultural growth and food security. It is because of the lack of these basic elements that the green revolution is not yet a reality in many (regions of) developing countries around the world although better technologies and options for increased productivity are available now more than ever before (Paroda 2004). See also Box III.2.6.

K. Ramesh (✉)
IHBT(CSIR), Palampur, India; IISS(ICAR), Bhopal, India
e-mail: ramechek@yahoo.co.in

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_10,

Box III.2.6

The success story of Integrated Pest Management (IPM) in rice in Indonesia provides an interesting case of research and development efforts that were well planned, coordinated and executed at the national level involving rice researchers, extension workers and farmers in a participatory approach. The IPM program in Indonesia reflects a cost-effective model, wherein complex methodologies have been institutionalized on a large scale at the level of the farmers' field, resulting in tangible benefits. With technical backstopping of FAO, the Rice IPM Program, to begin with, involved 100,000 farmers during 1989–1991 and finally around 1,000,000 farmers by 1998. The IPM program ultimately resulted in an increase in rice yields despite considerable reduction in the inputs of pesticides. It is also significant that the IPM strategy mainly relied on active participation of farmers, as well as trained and competent experts, with access to the best information and knowledge relating to various components of IPM. There were resistant varieties, clean cultivation, timely planting, use of bio-pesticides and bio-control agents according to threshold values for different pests and the need-based use of safe chemical pesticides. Ultimately, the farmer to farmer training program became the basis for such impressive success, which later on many countries including India, Philippines, Malaysia etc. tried to follow (Paroda 2004). This would ensure further decisions for efficient use of agricultural inputs viz., planting time, water storage, irrigation scheduling, fertilizer application, harvest and storage of grains.

In the developing world spreading and intensifying environmental hazards pose new challenges with agrometeorological components: intensification of low external input agriculture; increased effects of climate variability, deforestation, wind erosion and desert encroachment, water erosion, more agricultural use of sloping lands, migration into vulnerable areas, labour scarcity at crucial moments in the growing season and new insect pests are all among such new environmental hazards. The science of agrometeorology and its applications will have to contribute to development of operational knowledge to cope with these new hazards and their consequences, to obtain sustainable and economically viable agricultural development also in these parts of the world (WMO 2008). Almost all these issues have components of efficient use of agricultural inputs, to the waste of which these environmental hazards contribute very much.

In the industrialized world and in some parts of the newly industrializing world, intensive monocropping agriculture, in some cases including animal husbandry, has an increasing, cumulative, deteriorating effect on the environment in which agricultural production takes place and on soil, air and water quality. Moreover, there often is an influence of industrial output and waste, in different forms, on agricultural undertakings. Programmes have to be further developed in the industrialized world to diminish inputs into agriculture and to reduce the damage from the inputs used, from air pollution by components such as methyl bromide and nitrous fertilizers and from outside hazards (WMO 2008). Again efficiency of the inputs used will now count much more.

Cropping management through efficient use of agricultural inputs necessarily encompasses a wide range of decision-making steps, each of which has to be implemented at an optimum time. The main strategic decisions for which the climate information is needed include identification of appropriate choices of crops, water management, fertilizer usage, timing of harvest, pest management and other management practices. The tactical decisions incorporate a wide range of day-to-day operational decisions concerning soil, crop and water management such as sowing, cultivation, spraying and irrigation scheduling.

Inter- and intra-seasonal variations in climate carry considerable impact on the timing as well as efficiency of routine agricultural operations such as planting, weeding and harvesting, and they also determine the efficacy of application of inputs such as fertilizers, insecticides and pesticides (Sivakumar 2006). For many farmers, in developing and developed countries alike, the cost of providing energy inputs (in land preparation, weeding, ridging, fertilizer application, plant protection and harvesting) is prohibitive unless the efficiency of such inputs is certain to be high. Agricultural meteorology can make a significant contribution to the efficient scheduling of such energy inputs (WMO 2008).

Recent advances in understanding El Nino Southern Oscillation (ENSO) based seasonal climate forecasts have raised hopes for better agriculture management in Southern Africa (Phillips et al. 2001). Integration of climate forecast information with agricultural management would better equip farmers to make informed decisions and reduce food insecurity (increasing production) and improves livelihoods (Chikoore and Unganai 2001). Sonka et al. (2006) discuss the evaluating climate information as a strategic (input) resource.

The climate information available in Kenya indicated that the most vulnerable areas are expected to be the arid and semi-arid lands (ASALs), where frequency and severity of both droughts and floods is expected to increase (Ongwae and Karanja 2005). This information may efficiently be utilized through selection of crops and water management options for efficient use of agricultural inputs. Field based minor water storage decisions will ensure crop productivity as well as efficient use of fertilizer inputs as most of the fertilizer inputs show their potential only when water is available. The agronomic potential of fertilizer use in a country is determined by factors like climatic environment, genetic characteristics of crops, and use of inputs other than fertilizers (Desai 1988).

Farmers routinely make critical climate-sensitive agricultural and livelihood decisions months before the impacts of climate are realized. Potential applications include: selection of livelihood activities, crops and cultivars; allocation of land and household labor; soil, water, crop, livestock and forage management. For integrated pest management, see Box III.2.6. The ability to anticipate rainfall before or early in the growing season reduces one of the barriers in monocropping to invest in fertilizers, and presents opportunity for increasing the efficiency of both water and nutrients through adaptive fertilizer management (Hansen et al. 2004).

There are a number of annual crops raised as monocrops (e.g. rice and wheat) that are staple food. According to FAO, the global rice requirement in 2025 will be of the order of 800 million tonnes (Swaminathan 2006). The duration to maturity in annual crops depends on temperature and/or daylength. Strategic use of climate information as input may play a role in these crops. Climate change and related rise in global temperature are serious causes of concern, in these crops. A rise in air temperature may shorten the duration of the growing period and cause a shift in area of cultivation.

Simple management options to counteract the warming effect are changes in sowing dates and use of longer season cultivars (Olesen et al. 2000; Tubiello et al. 2000; van Ittersum et al. 2003) which are non monetary inputs. Pilot studies undertaken in many parts of the SADC region to investigate the utility of climate information in agricultural management revealed that farmers require input information about agronomic recommendations in terms of which crop varieties to grow (Chikoore and Unganai 2001). Spikelet sterility, a major problem in rice due to high temperature can be managed through March planting and use of less susceptible varieties like Annapurna and N-22 under Cuttack, India conditions (Krishnan 2006).

In a survey of Zimbabwean farmers on the use of climate information, Phillips et al. (2000) noted that the management strategies often cited by farmers when a forecast is available, include choice of cultivars, timely planting and altering quantity of monetary inputs. To cope with climate variability, farmers have developed a wide range of management practices like pre-monsoon dry seeding and stubble mulching (Selvaraju et al. 2004). In a case study, Selvaraju et al. (2004) found that for some communities (e.g. Avinashi), the decision between cotton and peanut is a response to climate forecasts and farmers considered it essential to managing the risk of crop failures in India. Most vegetable producers identified irrigation as an important means to reduce frost injury. Some farmers said that climate information could help them position better their crops within the landscape of their planting fields. For example, during a cold and dry period, farmers would plant their crops along low-lying areas (Canales et al. 2005).

References

Canales G, Coles B, Cornejo C, Fletcher T, Manganyi T, Owuso K, Painter K, Pellish H, Stonerook E, Wilsey D (2005) Perceptions and attitudes of smallholder farmers in north central Florida regarding the potential usefulness of seasonal climate forecasts. Publication of the Southeast Climate Consortium Technical Report Series: SECC-50-003, Gainesville. http://agroclimate.org/secc/pdfpubs/SECC05-003.pdf

Chikoore H, Unganai L (2001) Integrating climate forecast information in agricultural management: a perspective from Southern Africa. Presentation at the Open Meeting of the Global Environmental Change Research Community, 6–8 October, Rio de Janeiro. Socioeconomic Data and Applications Center (SEDAC), Center for International Earth Science Information Network (CIESIN), Columbia University, New York, no pages

Desai GM (1988) Policy for rapid growth in use of modern agricultural inputs. Chapter 12 In: Mellor JW, Raisuddin A (eds) Agricultural price policy for developing countries. IFPRI, John Hopkins University Press, Washington, pp 204–218. http://www.ifpri.org/pubs/books/Mellor88/Mellor88ch12.pdf.

Hansen JW, Dilley M, Goddard L, Ebrahimian E, Ericksen P (2004) Climate variability and the millennium development goal hunger target. IRI Technical Report No. 04-04, The Earth Institute of Columbia University, New York, no pages

Krishnan P (2006) Effect of high temperature stress on growth and yield components of rice. In: Abstracts of the second international rice congress, New Delhi, p 458

Olesen JE, Jensen T, Petersen J (2000) Sensitivity of field-scale winter wheat production in Denmark to climate variability and climate change. Clim Res 15:221–238

Ongwae J, Karanja F (2005) Coping with drought and climate change in Kenya. The coping with drought and climate change project advisory committee meeting held at UNDP/DDC, Nairobi, no pages

Paroda R (2004) Scaling-up: how to reach a billion resource-poor farmers in developing countries. Proceedings of the 4th International Crop Science Congress, Brisbane. http://www.cropscience.org.au/icsc2004/plenary/4/223_paroda.htm

Phillips J, Unganai L, Makaudze E (2000) Changes in crop management in response to the seasonal climate forecast in Zimbabwe during a La Nina year. Proceedings of the International Forum on Climate Prediction, Agriculture and Development, IRI, Palisades, New York, pp 213–216

Phillips JG, Makaudze E, Unganai L (2001) Current and potential use of climate forecasts for resource-poor farmers in Zimbabwe. In: Impact of El Nino and climate variability on agriculture. ASA, CSSA & SSSA. ASA Special Publication 63, Madison, pp 87–100

Selvaraju R, Meinke H, Hansen J (2004) Approaches allowing smallholder farmers in India to benefit from seasonal climate forecasting. In: New directions for a diverse planet. Proceedings of the 4th International Crop Science Congress, Australia. www.cropscience.org.au

Sivakumar MVK (2006) Dissemination and communication of agrometeorological information – global perspectives. Meteorol Appl 13(S1):21–30. Abstract: http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=762752&fulltextType=RA&fileId=S1350482706002520

Sonka ST, Hofing SL, Changnon SA (2006) Evaluating information as a strategic resource: An illustration for climate information. Agribus 4:475–491

Swaminathan MS (2006) Science and shaping the future of rice. In: Abstracts of the second international rice congress. New Delhi, p 1

Tubiello FN, Donatelli M, Rosenzweig C, Stockle CO (2000) Effects of climate change and elevated CO_2 on cropping systems: model predictions at two Italian locations. Eur J Agron 13:179–189

van Ittersum MK, Howden SM, Asseng S (2003) Sensitivity of productivity and deep drainage of wheat cropping systems in a Mediterranean environment to changes in CO_2, temperature and precipitation. Agric Ecosyst Environ 97:255–273

WMO (2008) Overview of the Agricultural Meteorological Programme. http://www.wmo.ch/pages/prog/wcp/agm/overview/Overview_en.html

III.2.1.(e) Selection of (Changes in) Livestock Management Patterns: Monocropping

Kees Stigter

Not too long ago, North American milk costed six times as much to produce as New Zealand milk (Nation 2004). One pound of dry matter from quality pasture could replace one pound of dry matter from grain at one-fourth to one-fifth the cost (Nation 2004). Grain-finished North American beef costed three times as much as grass-finished beef from Argentina, Australia and New Zealand (Nation 2004). Agrometeorological information has impact on grass ecology and management (e.g. Babushkin and Lebed 2002; Lebed et al. 2004) as well as fodder crops management (examples in Vilela et al. 2003 and Kleschenko et al. 2004).

Grass composition basically is a matter of initial local succession phases and grazing and other management (Ruiz-Vega 1994; Rinehart 2006). Brereton et al. (1994) shows for example for temperate zone legumes where each species would achieve dominance in competition and out-produce other pasture species with respect to environmental factors. Sheer (that is other than species) monocropping applies here only to the growing of fodder crops (e.g. soya bean in Al-Hazim et al. 1996; oats, millet, sorghum, maize in Vilela et al. 2003). The low nutrient status of soils, and the loss of organic matter (through continuous cropping, burning and overgrazing) and nutrients (erosion and leaching), are key issues also in livestock management. Farming systems, especially combinations of crops and livestock, also influence management options (DFID 2002).

However, also in livestock management itself "monoherding" one type of animal (e.g. Babushkin and Lebed 2002) and multiple species "herding" (e.g. Lebed et al. 2004) can be distinguished. In both contexts international experience and recent research in rangeland ecology suggest that the key to the sustainability both of livelihoods and of grassland environments is to support or promote the livestock mobility to the maximum extent possible, allowing producers to respond to widely variable forage growth over time and from place to place (Voegele 2001). In China (e.g. Voegele 2001) as well as in Africa (e.g. Klare 2006) serious resource conflicts

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_11,

may be consequences of such livelihood policies (see Box III.2.7). Agrometeorology could have assisted in improving resource sharing solutions at an early stage (Stigter 2008).

Box III.2.7

In one of my Roving Seminars (KNMI 2009) I state that it is these days recognized that sustainable land management is predominantly a conflict resolution issue among the major stakeholders. To understand the starting of conflicts like in Darfur, Sudan, one must understand that the frequency and severity of these conflicts are rising because of the rapidly increasing competition for natural resources. Egeimi et al. (2003), working for SOS Sahel (UK) in Khartoum, Sudan, have written about this with respect to pastoralism. Though customary law states that agricultural land after harvest is subject to public grazing, during the crop growing period no animals are allowed to enter the fields. Such periods may coincide with the passing of the herds of the pastoralists and the time of the greatest pressure on the pastoral resources in the region.

Conflicts between pastoralists and resident farmers over crop damage are increasing, that are normally settled by the village sheikhs, who are responsible for estimating the damage and determining the appropriate fine. The conflicts are normally due to the increased number of animals in the area, as well as the expansion of the productive fields into areas which were previously used for grazing and livestock corridors, in addition to dwindling land and water resources due to climate change. In the parts of Sudan we are talking about, like Darfur and Kordofan, sophisticated systems are used for resolving conflicts of all types, which draws heavily on the Koran and the teaching of the Prophet Mohammed. But one of the greatest threats to the traditional conflict resolution systems is the growing severity and frequency of conflicts, caused by decisions of competing authorities over natural resources (Egeimi et al. 2003). This is how the Darfur problems got started, but then ethnic, religious, tribal and other factors ((geo-)political, socio-economical), crept in, undermining any bilateral agreements between groups.

References

Al-Hazim S, Biswas BC, Hubbard KG, Sastry PSN (1996) Definition of agrometeorological information required for field and bush crops. CAgM Report 70. WMO/TD 757, Geneva, 97 pp

Babushkin OL, Lebed LV (2002) Validation of information requirements on livestock and pasture production in arid and semi-arid regions. CAgM Report 86. WMO/TD 1134, Geneva, 76 pp

Brereton AJ, Danielov SA, Scott D (1994) Agrometeorology of grasslands for middle latitudes. CAgM Report 59. WMO/TD 616, Geneva, 75 pp + figs.

DFID (2002) Soil Fertility and Nutrient Management. ODI Keysheet -Resource Management No. 7. http://www.keysheets.org/green_7_soils.pdf

Egeim O, Mahmood MA, Sid Ahmed A (2003) Conflict transformation: pastoralists and settled farmers. COMPAS Mag 9:22–23

Klare MT (2006) The coming resource wars. http://www.energybulletin.net/13605.html

Kleschenko A, Grom L, Ndiaye M, Stefanski R (2004) The impacts of agrometeorological applications for sustainable management of farming, forestry and livestock systems. CAgM Report 92. WMO/TD 1175, Geneva, 70pp

KNMI (for Netherlands Government, compiled by Kees Stigter, second update, 2009) Capacity building in the area of agrometeorological services through roving seminars. Document originally distributed and presented as CAgM-XIV/INF. 4 at the XIVth Session of the WMO CAgM, New Delhi, October/November 2006, 19pp

Lebed LV, Gandega Y, Rijks D (2004) Impact of agrometeorological information on rangeland and pasture ecology and management. CAgM Report 96. WMO/TD 1229, Geneva, 24pp

Nation A (2004) Quality pasture: how to create it, manage it, and profit from it, 4th reprint. http://www.nebsusag.org/resources/res_lvstk.htm

Rinehart L (2006) Pasture, rangeland and grazing management. ATTRA-National sustainable agriculture information services. http://attra.ncat.org/attra-pub/PDF/past_range_graze.pdf

Ruiz-Vega J (1994) Agrometeorology of grass and grasslands in tropical and sub-tropical regions. CAgM Report 57. WMO/TD 614, Geneva, 39pp

Stigter K (2008) Agrometeorological services under a changing climate: old wine in new bags. WMO Bull 57:114–117

Vilela L, Macedo MCM, Martha Jr GB, Kluthkouski J (2003) Crop-livestock integration benefits. EMBRAPA. http://www.fao.org/ag/agp/agpc/doc/integration/papers/integration_benefits.htm

Voegele J (2001) Combating desertification in western China: a policy perspective. http://lnweb18.worldbank.org/ESSD/ardext.nsf/17ByDocName/CombatingDesertificationinWesternChinaa PolicyPerspective1/$FILE/combatingdeserticationchinapaper.pdf

III.2.1.(f) The Development of Microclimate Modification Patterns: Monocropping

Kees Stigter

We deal here with the strategic use of climate information in the adoption of microclimate modification techniques in monocropping (e.g. Barfield and Gerber 1979). This is about decreasing or increasing the exposure of surfaces, either the actual soil surface or the more composite surfaces including above surface living and dead material, to radiation, precipitation and wind and/or changing the original properties of (composite) surfaces, resulting in an alteration of the impact of these large scale weather elements (Stigter and Darnhofer 1989). On-farm examples may be found in Box III.2.8.

Box III.2.8

In recent WMO and locally funded weather and climate related educational meetings with farmers in Andhra Pradesh, India, virtually in each village the farmers had questions and/or got advice on microclimate issues (Murthy 2008). It shows the importance of this kind of agrometeorological services. The following matters were handled with the farmers in demonstrations or other discussions (WMO 2010):

– soil moisture conservation or drainage techniques (as manipulations) to diminish yield reductions in crops at different stages that either will suffer from rain or need it (the "Onion-Bengal gram problem" in Chandur Village);
– changing the moisture conditions around stored paddy by spraying it with 2% common salt (as manipulation) that absorbed the moisture and kept the conditions at the seed's surfaces such that germination due to rain was virtually prevented (in Yemmangandla Village);

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_12,

– sun drying of groundnut pods (as microclimate management technique) to protect kernels from being affected by aflatoxins and to improve seed quality (in Loddipally Village);
– weather based top dressing of fertilizers (as microclimate management technique) to diminish financial losses and air and soil pollution when using fertilizers unnecessarily (in Vuyyalawada village);
– reduction of red gram crop density (as microclimate manipulation technique) to achieve optimal yields because sparse crops did better under more rain than normal (in Siddaramapuram village);
– soil moisture conservation techniques, where much rain is wanted in orange growing on red soils and drainage improving techniques were little rain is needed to grow them on black soils (both as manipulation techniques) (in Krishnamreddipally village);
– various storage and staking structures (Paddy Bins, as microclimate manipulation techniques) to protect produce from weather risks and uncertainties like cyclonic rains, heavy winds, excessive air humidity etc. (in Dendulur village);
– tying up of sugarcane crop to protect the crop from cyclonic winds (as microclimate manipulation technique) (in Gopannapalem village);
– rain water harvesting (as microclimate manipulation technique) for vegetable crops (in Kandukur village).

Farmers throughout the world are traditionally practising microclimate management and manipulation (e.g. Stigter 1985, 1987, 1988; Reijntjes et al. 1992; Stigter et al. 1992). The theoretical and experimental bases were laid long ago and further developed over the years (e.g. Stigter, 1994a; Geiger et al. 1995), making it possible to understand, improve and design modification techniques. Use and applications were reviewed by Stigter (1994b), who with respect to monocropping handled seasonal case studies related to changes with development stages and the influence of cultural practices.

In our drive to use climate prediction and response farming techniques (e.g. Harrison et al. 2007), it is easily forgotten that design, transfer and – preparedness for – adoption of microclimate modification (management (e.g. Kipkorir et al. 2007) and manipulation (e.g. Devine and Harrington 2007)) patterns can also be agrometeorological services. This can avoid or relief crop stresses in permanent or semi-permanent production or even in farming systems adaptation strategies in monocropping (Stigter and Weiss 1986; WMO 2006; Stigter 2007).

A recent example comes from China (Stigter et al. 2008). Stigter (2006) described and discussed already earlier the example of water melons grown in an improved microclimate created by covering sandy soil with a mulch of 8–10 cm of pebbles collected from river beds, explaining the wind erosion protection, the soil surface evaporation prevention and the warming of the seed bed so created (see also

Sect. I.5.4). Most of the few rains fall in autumn. The pebbles protect against evaporation of this water for use in early spring sowing. Without the mulching with pebbles, the soil could be dry till half a meter depth in spring.

It appears that the seeds are brought into holes in the layer of pebbles that remain a cavity, over which plastic is brought by some farmers. It has been measured that at the bottom of such covered cavities the soil surface temperatures can be in the order of 5° higher than at the pebble surface, particularly at night. Because of the importance of early sowing due to the length of the growing season, this can be an essential frost protection issue of the method (Stigter et al. 2008). This case is also dealt with in detail in Part II of this book (Agrometeorological Service Case II.C.III).

References

Barfield BJ, Gerber JF (1979) Modifications of the aerial environment of crops. ASAE Monograph No. 2. American Society of Agricultural Engineers, St. Joseph, Michigan, 538pp

Devine WD, Harrington CA (2007) Influence of harvest residues and vegetation on microsite soil and air temperatures in a young conifer plantation. Agr For Meteorol 145:125–138

Geiger R, Aron RH, Todhunter P (1995) The climate near the ground, 5th edn. Vieweg, Braunschweig, 528pp

Harrison M, Kanga A, Magrin GO, Hugo G, Tarakidzwa I, Mullen C, Meinke H (2007) Use of seasonal forecasts and climate prediction in operational agriculture. CAgM Report 102, WMO/TD 1344, Geneva, 81pp

Kipkorir EC, Raes D, Bargerei RJ, Mugalavai EM (2007) Evaluation of two risk assessment methods for sowing maize in Kenya. Agr For Meteorol 144:193–199

Murthy VRK (2008) Report on the project entitled "WMO-ANGRAU-DST sponsored Roving Seminars on Weather, Climate and Farmers", available on the INSAM website (www.agrometeorology.org) under "Needs for agrometeorological solutions to farmer problems"

Reijntjes C, Haverkort B, Waters-Bayer W (1992) Farming for the future. An introduction to low-external-input and sustainable agriculture. Macmillan/ILEIA, London/Leusden, 250pp

Stigter CJ (1985) Traditional microclimate management and manipulation in Tanzanian agriculture. A synopsis. Neth J Agr Sci 33:303–305

Stigter CJ (1987) Tapping into traditional knowledge. In: African revival. Rediscovering their own resources. (Centerpiece papers) CERES. FAO-Rev 20(3):29–32

Stigter CJ (1988) Microclimate management and manipulation in traditional farming. CAgM-Report No. 25, WMO/TD-No 228, 20pp. + 6 Append. WMO, Geneva. [French, Spanish and Russian translations available]

Stigter CJ (1994a) Micrometeorology. Chapter 5. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York, pp 59–72

Stigter CJ (1994b) Management and manipulation of microclimate. Chapter 27. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York, pp 273–284

Stigter K (2006) Agrometeorological services in various parts of the world, under conditions of a changing climate. Austin Bourke Memorial Lecture presented in the Royal Irish Academy, Dublin, in the evening of 2 March. Extended Abstract available on the INSAM website under "Accounts of Operational Agrometeorology"

Stigter CJ (2007) From basic agrometeorological science to agrometeorological services and information for agricultural decision makers: a simple conceptual and diagnostic framework. A Guest Editorial. Agr For Meteorol 142:91–95

Stigter CJ, Weiss A (1986) In quest of tropical micrometeorology for on-farm weather advisories. A Guest Editorial. Agr For Meteorol 36:289–296

Stigter CJ, Darnhofer T (1989) Quantification of microclimate near the soil surface. Appendix F. In: J.M. Anderson and J.S.I. Ingram (eds) Tropical soil biology and fertility: a handbook of methods, IUBS/UNESCO, (MAB). C.A.B. International, Wallingford, pp 144–157

Stigter CJ (co-ord. & ed.), Karing PH, Stigter CJ, Chen W, Wilken GC (1992) Application of microclimate management and manipulation techniques in low external input agriculture. CAgM Report No. 43, WMO/TD-No. 499, Geneva, 192pp

Stigter K, Liu Jing, Zheng Dawei, Ma Yuping, Wang Shili (2008) Further identification of two agrometeorological services in Ningxia Autonomous Region, Western China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology"

WMO (2006) Commission for Agricultural Meteorology (CAgM). The first fifty years. WMO 999, Geneva, 44pp

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by Stigter CJ. WMO, Geneva, in print

III.2.1.(g) Designs of (Changes in) Protection Measures Against Extreme Climate: Monocropping

Kees Stigter

Designs of lasting protection measures against extreme climate and of changes in such protection measures do need the strategic use of climate information (e.g. Cooperative Programme on Water and Climate 2007; China's National Climate Change Programme 2007).

Understanding vulnerabilities to changes is a critical part of estimating future climate change impacts on human health, society and the environment (USEPA 2007). Changing vulnerabilities may have been as important as changing climatic conditions (e.g. Baethgen 1997; Athanasiou and Baer 2002; Enviropedia 2007).

Lassa (2006) distinguished four protection policy issues that were used by Stigter et al. (2007) to differentiate between income groups of farmers with respect to services and by Rathore and Stigter (2007) as coping/protection strategies: (i) mitigation practices; (ii) disaster preparedness; (iii) contingency planning and responses and (iv) disaster risk mainstreaming. All four are in need of basic strategic climate information.

Although mitigation of climate change itself is an essential issue (e.g. Lewis 2007; Parts I and IV of this book) here we are talking about designing protection against climate impacts (e.g. IFRC 2007; Borgia et al. 2008) and mitigation of such impacts (e.g. managing new and existing mangrove belts seems promising as a protection against coastal storms and to encourage sedimentation in Bangladesh, see Koudstaal et al. 1999; for designs for combating coastal hazards in New Zealand see Ministry of Environment 2004; for improved defense against floods in Europe see Van Schaik 2007).

It are most often the vulnerabilities that can be seriously reduced by designing temporary or permanent measures of impact reduction and preparedness. But the impacts should be obtainable in quantitative form (Box III.2.9). It has been proven that actual disaster risk mainstreaming contains the other three coping/protection

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_13,

strategies (e.g. NEF 2006 for Latin America; ADRC 2007 for Asia and the Pacific; Kelly and Khinmaung 2007 for Africa).

Box III.2.9

One of the major problems in dealing with preparing (changes in) strategies to deal with extreme weather events in agriculture, rangelands and forestry was the lack of systematic and standardized data collection from disasters (Rathore and Stigter 2007; Borgia et al. 2008). Until recently there was no recognized and acceptable international system for disaster-data gathering, verification and storage. The current state of agricultural systems can be routinely collected in an information system. For extreme factors of geophysical origin, detailed quantitative and georeferenced data about their characteristics are known almost immediately after the event. Some pre- and post-impact data are also rapidly available through remote sensing. If impact models were readily available at the time of a disaster, this set of knowledge could be used to model impacts and to generate preliminary assessments very rapidly (Borgia et al. 2008). Very recently FAO has tried to do something about this (Borgia et al. 2008 on RADAR). The RADAR report proposes to move from empirical assessments towards model approaches. Once an event strikes a region, the user of the procedure should rapidly collect all available georeferenced and quantitative data on the event and the region. Subsequently, a Disaster Information Management System (DIMS) that integrates physical models, knowledge-bases, databases and GIS can be used to assess the short- and long term agricultural impact of the event. The procedure combines model analysis, based on physical simulation of the disaster, and empirical analysis, using people's records of the environmental disruption after the event. Both analyses may be used alone or concurrently and they can be updated in real time to improve the assessment. The output of the analyses is the geographical distribution of the intensity of the event, which is then used to compute the integrated impact (the loss) to agriculture produced by the disaster (Borgia et al. 2008).

For some disasters like drought, lack of appropriate definition of natural disaster itself is a problem. Definitions of natural disasters are based on the need to respond to development and a humanitarian agenda. Different disasters can be classified as different types by different databases. For example, a flood which was a consequence of severe wind storm, may be recorded as one or the other. Flood (as related to rains) and drought may be long-lasting (Gommes and Nègre 1992), but in Asia their shorter durations are more common. Rathore and Stigter (2007) therefore decided to deal for Asia with those chosen by Salinger et al. (2000): (i) high intensity rainfall and floods, (ii) tropical storms, tornadoes and strong winds, (iii) extreme temperatures including heat waves and cold waves, (iv) droughts and (v) wildfires and bushfires. Challenges to disaster risk mainstreaming and to mitigation practices need to be dealt with for each of these events, while challenges to contingency planning and to basic preparedness have so much in common for these events that they can be dealt with in more general terms (Rathore and Stigter 2007).

References

ADRC (2007) Asian Disaster Reduction Centre. In particular Asian Disaster Reduction & Response Network. http://www.adrc.or.jp and http://www.adrrn.net/index.asp

Athanasiou T, Baer P (2002) Dead heat: global justice and global warming. An Open Media Book. Seven Stories Press, New York. http://www.ecoequity.org/docs/deadheat.htm

Baethgen WE (1997) Vulnerability of the agricultural sector of Latin America to climate change. Clim Res 9(1–2):1–7

Borgia A, Gommes R, Bernardi M, Kanamaru H (2008) Rapid agricultural disaster assessment routine (RADAR). FAO Environment and Natural Resources Series 12. FAO, Rome, 88pp

China's National Climate Change Programme, 2007. National climate change programme. http://www.china.org.cn/english/environment/213624.htm

Cooperative Programme on water and climate, 2007. Bridging water and climate for development. Delft, Netherlands. http://www.waterandclimate.org/

Enviropedia (2007) Extreme weather. http://www.enviropedia.org.uk/Global_Warming/Extreme_Weather.php

Gommes R, Nègre T (1992) The role of agrometeorology in the alleviation of natural disasters. Agrometeorology Series Working paper No 2. FAO, Rome, 22 pp

IFRC (2007) Efforts must be made to pre-empt catastrophic effects of climate change. International Federation of Red Cross and Red Crescent Societies. http://www.ifrc.org/Docs/News/pr07/1707.asp

Kelly C, Khinmaung J (2007) Prepare to live. Strengthening the resilience of communities to manage food security in the Sahel region. Tearfund. http://www.tearfund.org/webdocs/Website/campaigning/policy%20and%20research/Prepare%20to%20Live%20summary.pdf

Koudstaal R, Werners SE, Ahmed AU (1999) Considering adaptation to climate change towards a sustainable development of Bangladesh. http://www.mungo.nl/CC_Bangla.htm

Lassa J (2006) New direction needed for coping with disasters. Jakarta Post (Indonesia), January 16, p 6

Lewis MC (2007) The IPCC reports: relationship to planning. American Planning Association. http://www.planning.org/energy/ipcc.htm

Ministry of Environment (2004) Coastal hazards and climate change: a guidance manual for local government in New Zealand, ME512, New Zealand. http://www.mfe.govt.nz/publications/climate/coastal-hazards-may04/index.html

NEF (2006) Up in smoke? Latin America and the Caribbean: the threat from climate change to the environment and human development. New Economics Foundation. http://www.neweconomics.org/gen/uploads/15erpvfzxbbipu552pnoo1f128082006213002.pdf

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties in Asian regions. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 53–69

Salinger JJ, Stigter CJ, Das HP (2000) Agrometeorological adaptation strategies to increasing climate variability and climate change. In: Sivakumar MVK, Stigter CJ, Rijks DA (eds) Agrometeorology in the 21st century – needs and perspectives. Agr For Meteorol 103:167–184

Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi YM (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 171–190

US Environmental Protection Agency (2007) Extreme events. http://epa.gov/climatechange/effects/extreme.html

Van Schaik H (2007) Innovations in risk management in Europe. http://www.waterland.net/showdownload.cfm?objecttype=mark.hive.contentobjects.download.worddoc&objectid=D7AEFF0C-A178-CD05-465A25EA8D61880F

III.2.2 Coping with Climate Variability and Climate Change

III.2.2.(i) Improving the Issuing, Absorption and Use of Climate Forecast Information in Agricultural Production: Monocropping

Ajit Govind and Kees Stigter

In an agrarian economy, an ideal way to cope with climate change/climate variability is to develop strategies/plans that are implemented at multiple spatial (national, provincial, county/district or at grass-root/farm scales) and temporal (annual, seasonal or daily) scales. This ensemble of strategies in the form of agro-meteorological advices/services should be implemented simultaneously to get the maximum benefit to the local farmer and the economy (e.g. Hellmuth et al. 2007). Unfortunately, the term "risk management" remained in use here and elsewhere, while all evidence shows that farmers in poor countries have the largest difficulties to cope with climate risks and uncertainties and do not manage these risks at all. The issue is preparedness in various forms (Rathore and Stigter 2007).

"Agrometeorological services for agricultural production" and "agrometeorological support systems to such services" are critical in this regard, as long as they are taking place within the livelihood of farmers (Stigter et al. 2000; Stigter 2005, 2008). It should be considered that not only scientific or operational limitations, but also political, economic, socio-cultural and financial factors are important aspects (Stigter et al. 2000; Stigter 2008). Climate forecasting information is only one kind of information that only under well understood conditions of probability, uncertainty and limitations can be brought to farmers (see also Box III.2.10).

Box III.2.10 (Contributed by Kees Stigter)

The success of long-lead El Niño and La Niña forecasts in North America has led to enormous interest in seasonal prediction worldwide, including in developing countries, and has led in many instances to unrealistic expectations about them. The fact remains that climate predictions have at best modest skill, and in many circumstances no or marginal skill, in the absence of a strong ENSO signal. See also Chap. IV.12. Nevertheless, it has been argued forcefully by a number of groups that these sets of forecasts have tangible

A. Govind (✉)
College of Forestry, Oregon State University, Corvallis, OR, USA
e-mail: ajit.govind@oregonstate.edu

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_14,

economic value for a class of decision-makers and users. The credibility of the arguments depends on whether real decision-makers and users behave in the manner assumed in the models. Estimates of the uncertainty in forecast value for different forecast skills and realistic iterations of the forecasts/decisions have been made, with different simple assumptions about the psychology of the user (for example, the user abandons use of the forecast if the forecast was wrong two winters in a row).

The computed uncertainties cast considerable doubt on the utility of marginally skilful forecasts sets for individual users and provide a sense of what skill levels are necessary to increase likelihoods that relatively short sequences of forecasts/decisions will be of value. These levels turn out to be relatively high, comparable to the performance of the strong ENSO event "forecasts of opportunity." Including again the presently most common form of these forecasts, care should be taken that this agrometeorological service tool is not overestimated by wishful thinking. Much more case studies should be collected on actual attempts to use such forecasts and in what form this has been successful for which target groups of users under what conditions (WMO 2010). This will assist in the needed improvements of successful production, presentation and use of seasonal and other long term climate predictions (Livezey and Mayes 2004; WMO 2010).

Since farmers should be prepared to meet the vagaries of meteorological parameters on crop performance, *climate information* needs to be efficiently disseminated to them. Interesting examples may be found in recent reports on several years of identifying and researching of agrometeorological services in five provinces in China (Stigter et al. 2008a,b,c,d,e). This featured the importance of the art of reaching farmers with the information available/needed in the Chinese "cascade" system from Provincial Level, Sub-Provincial Level, County Level and Township Level to Village Level (Stigter et al. 2008a). At the lower levels, extension officers and village technicians must play an important role (see also Stigter et al. 2007). This should be compared with a system of Climate Field Schools as recently developed elsewhere in Asia (Winarto et al. 2008).

The use of climate forecasting was important in the examples of "Sowing advice for spring wheat depending on the frost melting condition in the autumn irrigated top soil in Bayabnaoemeng" (Stigter et al. 2008a); "Forecasting fungus disease conditions for wolfberries" (Stigter et al. 2008b); "Refined agro-climatic zoning used for planning of growing navel oranges, and protection advisory services after planting" (Stigter et al. 2008c); "Water saving irrigation determined by soil moisture forecasting for wheat farms in the Huang-Huai-Huai Plane, Henan" and "Forecasting peony flowering periods for various varieties and places in Luoyang city, Henan" (both in Stigter et al. 2008d) and "Early warning of low temperatures and less sunshine for plastic greenhouse crops in winter" (Stigter et al. 2008e).

A study was conducted in the Brazilian Amazon that examined the farmers' coping strategies in the in response to El Nino and the related weather events (Moran et al. 2006). It was concluded that hitherto, little attention was explicitly given to the impact of ENSO events by the farmers. This study deciphered the existence of a range of locally developed forecasting techniques and coping mechanisms that the farmers adopted even when they were ignorant about the physical reasons for the ENSO events. Increased access to scientific forecasts would greatly enhance the ability of the farmers to cope with El Nino related weather events that the farmers have sustained over the years (see also Box III.2.10). Moran et al. (2006) speculate that the distribution of an El Nino Prediction Kit at the end of the study and a series of workshops (such as climate field classes) may lead to better local information on rainfall variability and create a farmer-maintained grid of collecting stations to sensitize farmers to the variability of precipitation in the region, and on their property.

Box III.2.11 (Contributed by Kees Stigter)

An example of an organizational context in Africa is shown in that in 2003 the Drought Monitoring Centre of Nairobi was changed into the IGAD Climate Prediction and Applications Centre (ICPAC) in order to reflect better all its new mandates, mission and objectives. One of its three objectives is to improve the technical capacity of producers and users of climatic information, in order to enhance the input to and use of climate monitoring and forecasting products. Its mission is described as "fostering sub-regional and national capacity for climate information, prediction products and services, early warning, and related applications for sustainable development in the IGAD Sub-Region". The recent past climate over the Horn of Africa is provided through decadal, monthly and seasonal summaries of rainfall and drought severity and monthly temperature anomalies. The current state of climate is monitored and assessed using climate diagnostics and modeling techniques. These are derived from information on the state of the sea surface temperature anomalies over all the major ocean basins, surface and upper air anomalies of pressure, winds and other climate parameters.

The prediction products are provided through outlooks for a decade, month and season. Consensus pre-season climate outlook fora are also organised in conjunction with the major climate centres world-wide in order to derive a single consensus forecast for the region. An assessment of the vulnerability together with the current and potential socio-economic conditions and impacts (both negative and positive) associated with the observed and projected climate anomalies is also made on decadal, monthly and seasonal time scales. These products are disseminated to all NMHSs of the participating countries to serve as early warning information to a variety of sectoral users of meteorological information and products including policy makers, planners, health, energy, agricultural and water resource sectors, farmers as well as research institutes among others, where they can be used to establish services (WMO 2006).

One of the several effects of climate change is the increased occurrence of droughts (e.g. Hellmuth et al. 2007). In order to achieve self-reliance and reduce the impact of drought, there is a need for a national drought policy that supports the necessary research and educational infrastructure so that farmers, agri-business and rural communities can better anticipate and cope with droughts. Efficient drought policy and increased awareness makes the farmers more self-reliant making them "proactive rather than reactive" as seen in Australia and southern Africa (White 2000). There is a need for integrating drought forecasting and preparedness efforts, farmers' understanding of climate-crop interactions and interventions that support the capacity of resource-limited households. In the literature, there are several Africa-centered studies that have taken a household-level approach to understand farmer's perception to environmental change (e.g. Bratton 1987; Corbett 1988; Campbell 1999; Roncoli et al. 2001; Vogel and O'brien 2006). See also Box III.2.11 (WMO 2006).

Climate information, in addition to seasonal climate forecasts, is a potential tool for early-warning systems such as for the occurrence of pests, diseases and related weather conditions (e.g. Stigter and Rathore 2008; Stigter et al. 2008b). It is also required by applied agrometeorologists to assess the risks associated with the existing and newly developed plans to forecast pest and diseases, and to assess the impact of these techniques on productivity, profitability and sustainability in the event of climate change (Strand 2000).

Information has value when it is disseminated in such a way that the end-users get the maximum benefit in applying its content (Weiss et al. 2000). Applied agrometeorology should therefore explore the potential of new information and communications technologies to improved crop production (Stigter et al. 2007). The World Wide Web can play a critical role in the collection and transfer of information between the scientist and the farmers, especially in developed countries where the computer literacy and the economic and educational levels of the farmers are quite high (USA, Canada, Australia etc.). However, in developing countries, where the internet-mediated information transfer is practically difficult, strategies such as Multi-Purpose Community Telecentres (MCTs) will be the equivalent of an information hub (Weiss et al. 2000). Radio can be used to transfer information from MCTs to rural areas.

References

Bratton M (1987) Drought, food and the social organization of small farmers in Zimbabwe. Drought and hunger in Africa: denying famine a future. Cambridge University Press, Cambridge, pp 213–244

Campbell DJ (1999) Response to drought among farmers and herders in Southern Kajiado District, Kenya: a comparison of 1972–1976 and 1994–1995. Hum Ecol 27:377–416

Corbett J (1988) Famine and household coping strategies. World Dev 16:1099–1122

Hellmuth ME, Moorhead A, Thomson MC, Williams J (eds) (2007). Climate risk management in Africa: learning from practice. International Research Institute for Climate and Society (IRI), Columbia University, New York, 105pp. http://www.fanrpan.org/documents/d00255/1-Climate-risk_Africa_2007.pdf

Livezey RE, Mayes BE (2004) Value of climate forecasts with marginal to modest skill to real users. Climate Prediction Applications Science Workshop. March 9–11, Tallahassee. http://climateservices.coaps.fsu.edu/alpabstracts.doc

Moran EF, Adams R, Bakoyema B, Fiorini S, Boucek B (2006) Human strategies for coping with El Nino related drought in Amazonia. Clim Change 77:343–361

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties-regional perspectives: Asia. In: Sivakumar MVK, Motha R (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 53–69

Roncoli C, Ingram K, Kirshen P (2001) The costs and risks of coping with drought: livelihood impacts and farmers' responses in Burkina Faso. Clim Res 19:119–132

Stigter K (CJ) (2005) Building stones of agrometeorological services: adaptation strategies based on farmer innovations, functionally selected contemporary science and understanding of prevailing policy environments. Paper Presented at the Opening Keynote Lecture at the International Symposium on Food Production and Environmental Conservation in the Face of Global Environmental Deterioration (FPEC, 2004), Fukuoka. J Agric Meteorol (Japan) 60:525–528

Stigter CJ (2008) Agrometeorology from science to extension: Assessment of needs and provision of services. Agric Ecosyst Environ 126:153–157

Stigter K, Rathore LS (2008) How to organize coping with crop disease risks of farmers in poor countries. Paper presented at an Asian Pacific Network (APN) finalizing Workshop of the project "Climate and crop disease risk management: an international initiative in the Asia-Pacific Region" in Dhaka, Bangladesh, 10 till 14 February. Available on the INSAM web site (www.agrometeorology.org) under "Needs for agrometeorological solutions to farming problems"

Stigter CJ, Sivakumar MVK, Rijks DA (2000) Agrometeorology in the 21st Century: workshop summary and recommendations on needs and perspectives. Agric For Meteorol 103:209–227

Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi YM (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 171–190

Stigter K, Niu Baoliang, Yang Song, Hou Qiong, Zheng Dawei, Ma Yuping, Wang Shili (2008a) Recent identification of two agrometeorological services in Inner Mongolia Autonomous Region, Northern China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology"

Stigter K, Liu Jing, Zheng Dawei, Ma Yuping, Wang Shili (2008b) Further identification of two agrometeorological services in Ningxia Autonomous Region, Western China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology"

Stigter K, Xie Yuanyu, Liao Zhihui, Rao Qiusheng, Li Yingchun, Zheng Dawei, Wang Shili, Ma Yuping (2008c). Recent identification of two agrometeorological services in Jiangxi Province, Southern China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology"

Stigter K, Chen Huailiang, Yu Weidong, Liu Ronghua, Zheng Dawei, Wang Shili, Ma Yuping (2008d). Recent identification of two agrometeorological services in Henan Province, Central China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology"

Stigter K, Li Chunqiang, Zheng Dawei, Wang Shili, Ma Yuping (2008e). Further identification of two agrometeorological services in Hebei Province, China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology"

Strand JF (2000) Some agrometeorological aspects of pest and disease management for the 21st Century. Agric For Meteorol 103:73–82

Vogel C, O'brien K (2006) Who can eat information? Examining the effectiveness of seasonal climate forecasts and regional climate risk management strategies. Clim Res 33:111–122

Weiss A, Van Crowder L, Bernardi M (2000) Communicating agrometeorological information to farming communities. Agric For Meteorol 103:185–196

White DH (2000) Drought policy, monitoring and management in arid lands. Ann Arid Zone 39:105–129

Winarto YT, Stigter K, Anantasari E, Hidayah SN (2008) Climate field schools in Indonesia: coping with climate change and beyond. Low Ext Input Sust Agric (LEISA) Mag 24(4):16–18

WMO (2006) Drought monitoring and early warning: concepts, progress and future challenges. Brochure prepared by White D. WMO 1006, Geneva, 24 pp

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by Stigter CJ. WMO, Geneva, in print

III.2.2.(ii) The Sustainable Development and use of Agro-Ecosystems: Monocropping

Ajit Govind and Kees Stigter

Agro-ecosystems are ecosystems managed by farmers and hence there is control over the fluxes of mass and energy within these systems. Rising population growth on one hand and reduced acreages of farm-land on the other, particularly in the developing countries, have increased demands for the use of many of their natural resources (Bauhus et al. 2002; Stephens et al. 2003). For example, one estimate of the past suggested that the per capita arable land would decline from about 0.3 ha in 1990 to 0.23 ha by the year 2000, and is likely to decline to 0.15 ha by 2050 and 0.14 ha by 2100 (Lal 1991). Similarly other resources, such as water, soil organic matter etc., are likely to alter in availability. See also Box III.2.12. Under climate change, climatic resources (e.g. length of growing season, growing degree days etc.) will also change.

Box III.2.12

With the advent of new technologies, farm-mechanization, hybrid seeds, fertilizers and pesticide use, and also due to various government policies, agricultural productivity has substantially increased over the years. Although this increased productivity facilitated food sufficiency, there have also been confirmed significant costs associated with degradation of various resources such as topsoil (De Neergaard et al. 2008) and groundwater (Maqsood et al. 2005), shortages of water supply, expansion of agriculture into marginally producing areas (Agyemang et al. 2007). And there are also the increasing economic costs of agricultural production (Gobin et al. 2002; Wheeler 2008).

Considering these issues, there has been a growing concern among the scientific community about the sustainability of natural resources availability, environmental and agricultural productivity. Already Swindale (1988) indicated that sustainability is a balance between human needs and environmental

A. Govind (✉)
College of Forestry, Oregon State University, Corvallis, OR, USA
e-mail: ajit.govind@oregonstate.edu

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_15,

concerns. Sustainable agricultural systems remain productive over time and cater for the needs of current, as well as future generations, while conserving natural resources (NRC 1991). Considering the various definitions of sustainability/sustainable systems from the literature as for example compiled by Sivakumar et al. (2000), natural resources are the key factor in sustainable agriculture (see also Chap. IV.3 for basic considerations).

Crop simulation modeling is an ideal arena to do interdisciplinary research work of an agro-ecosystem. Predictive power of models can be used to better clarify the dynamics of various resources and the related feedback mechanisms of physical entities of an agro-ecosystem. This is particularly important in understanding the resource sustainability of high input agriculture. Socio-economic controls affecting agro-ecosystem resource dynamics and human power as a resource are still a challenge for quantification (e.g. Stigter et al. 2010).

Issues of sustainable use of various resources in agro-ecosystems have been dealt with quite thoroughly, directly or indirectly, in the literature (e.g. Lavelle 2000; Becker and Johnson 2001; Kropff et al., 2001; Schmidt and Lamble 2002; Bauhus et al. 2002; Stephens et al. 2003; Ding 2005; Van Calker et al. 2008; Lal 2008). The concept of sustainable development means an integrated management of landscape, where the exploitation of natural resources, including climate, plays a central role. Hitherto, amongst the natural resources that are essential for agricultural production, climate has received lesser attention (Sivakumar et al. 2000). In an applied meteorological context, one may discuss climate as a more important natural resource of a given agro-ecosystem than other natural resources such as soil or water, while these resources are directly or indirectly dependent on climate.

Many of the ecological implications of agricultural development require an improved understanding by stakeholders (farmers), decision makers (farmers, policy makers) and researchers (scientists and extension personnel) of interactions between the purely physical, biological and chemical components of the environment and the composite climatic components. The relationships between the productive capacity of resources and the adsorptive capacity of the environment are often not well understood by the stakeholders (Thomas 1988). Therefore it is important to encourage extension activities and the dissemination of agrometeorological knowledge as a first step towards sustainable resource utilization.

Among agro-ecosystem resources such as climate, soil, water, biological/genetic factors, socio-economic factors and institutional factors, climate is the most critical factor determining the sustainability of agricultural systems (Sombroek and Gommes 1996). Even the highest yielding, the most pest and disease resistant as well as fertilizer responsive variety can perform unsatisfactorily because biological responses are strongly controlled by conditions such as climate, soil fertility, soil moisture regimes, soil fertility etc (Senanayake 1991). There are unique environmental thresholds that control biological productivity. To have sustainable use of resources at the scale of an agro-ecosystem, it is required to identify, build up, and maintain the necessary physicochemical, bioecological and socio-cultural resources.

If the resources have to be used in a sustainable manner, they must be first identified in quantitative terms and then properly managed (Gommes and Fresco 1998). This can be achieved by doing an inventory of resources and budgeting their inputs, outputs and storage change components, within a given space and time span. The scarce resources at the agro-ecosystem-scale should be identified employing various methods such as socioeconomic surveys, precise measurements, geographic information systems (GIS) and remote sensing. Currently, sustainable resource management issues are focused on resources such as soil (fertility, moisture status, physical qualities), water (root zone moisture, rainfall duration and intensities), genetics (local varieties, pest and disease resistance). See also Box III.2.13.

Box III.2.13

Some of the current efforts to sustainably manage agro-ecosystems include preservation of genetic resources (Gepts 2006; Brindza et al. 2007), development of soil and water conservation strategies at all spatial and temporal scales (Sims et al. 1999; Zobeck et al. 2007; Teasdale 2007; Williams 2008; Rainford 2008), conservation of soil fertility and organic matter (Ewel et al. 1991; Szott et al. 1999; Mendham et al. 2002; Adediran et al. 2003), documentation and dissemination of indigenous knowledge (Stigter 1988; Stigter et al. 1992; Mohamed and Ventura 2000; Zurayk et al. 2001; Payton et al. 2003; Mbilinyi et al. 2005; Stigter et al. 2005; Aswani and Lauer 2006), and coping with climate change (Amissah-Arthur 2003; Stigter et al. 2005; Thomas 2008).

Since agrometeorological complexities differ across different spatial scales, plans developed for sustainable use of agro-ecosystem resources should essentially be implemented at multiple scales. This means that management activities have to be initiated at the farm-scale, village/county-scale, watershed-scale and agro-climatic zone-scales simultaneously, in order to have an efficient and sustainable resource management. Taking water as a scarce resource, for example, programs for rain water harvesting, for ground water recharge, for directing water to points of need, through the use of dams, retention and interception banks, for swales and channels, have to be planned well, considering the physical and socio-economic intricacies at all spatial and temporal scales. The optimal design and location of these structures require a thorough knowledge of the local ecological conditions, a detailed local knowledge of seasonal and topographical characteristics, and an understanding of the socio-cultural constraints and opportunities.

Watershed-scale governmental initiatives (or schemes) exist for the development of marginal agro-ecosystems, wastelands, degraded lands, drought prone areas and deserts. Considering the human dimensions of natural resource management, participatory processes are needed that seek to understand farmers' needs and motivations in ways which translate their knowledge into practical management solutions at the farm scale (e.g. Stigter et al. 2010). Participation of the stakeholders in geomatics-based policy development and planning can be effectively implemented through concepts such as participatory GIS (PGIS). PGIS has been used in various aspects of agriculture towards sustainable development such as scarce resource management (Miller et al. 2002); land-use and natural resource planning (Walker et al. 2002); conservation of natural resources (Meredith et al. 2002; Sieber 2002; Tulloch 2002); solving social problems associated with natural resources distribution (Wiener et al. 1995; Harris and Weiner 1998, 2002; Kyem 2002, 2004; Weiner and Harris 2003); social equity mapping (Kwan 2000); resource management and service access in the "First World" or among indigenous people (Bond 2002; Laitur, 2002) etc, to name some.

The role of traditional knowledge and indigenous technology in sustainable natural resource management is substantial (Mohamed and Ventura 2000). These are location specific often age-old practices that are efficient in delivering desired goals, preserving the resource base without much degradation (e.g. Stigter et al. 2005). These technologies are effective in making the best use of scarce agro-climatic resources in a sustainable manner. The use of indigenous technology is common in agro-forestry (Baldy and Stigter 1997; Breman and Kessler 1995; Ong and Huxley 1996) and other multiple cropping systems (Stigter and Baldy 1993; Baldy and Stigter 1997), agro-ecology (Altieri 1983), wind erosion control (Sivakumar et al. 1998), soil water balances (Sivakumar et al. 1991), integrated pest management (LEISA 1997), climatic risk in crop production (Muchow and Bellamy 1991) and post harvest systems (FAO 1987).

In sustainable use of resources in agricultural production, climate could be regarded as the driving variable for exploitation of plant, animal and soil resources and this is where agro-meteorologists can contribute. The highly site-specific nature of climatic or meteorological characteristics affecting the resource level directly or indirectly determines the feasibility and applicability of an indigenous technology in a given area. Rijks (1994) stressed the importance of planning, and the need for early warning for hazards, desert locust control, extrapolation of farming/cropping systems experiences and micro-environment modifications (indigenous knowledge). It is therefore of interest to refer to the practices of microclimate management in agro-ecosystems, developed to meet needs of sustainable farm-resource conservation (Stigter and Weiss 1986; Stigter 1988, 1994).

References

Adediran JA, De Baets N, Mnkeni PNS, Kiekens L, Muyima NYO, Thys A (2003) Organic waste materials for soil fertility improvement in the border region of the Eastern Cape, South Africa. Biol Agric Hort 20:283–300

Agyemang I, Mcdonald A, Carver S (2007) Application of the dpsir framework to environmental degradation assessment in northern Ghana. Nat Res Forum 31:212–225

Altieri MA (1983) Agro-ecology. The scientific basis of alternative agriculture. University of California, Berkeley, 162pp

Amissah-Arthur A (2003) Targeting climate forecasts for agricultural applications in Sub-Saharan Africa: Situating farmers in user-space. Clim Change 58:73–92

Aswani S, Lauer M (2006) Benthic mapping using local aerial photo interpretation and resident taxa inventories for designing marine protected areas. Environ Conserv 33:263–273

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. INRA, Paris; Science Publishers, Enfield (USA), Oxford; IBH Publishers, New Delhi, 237pp

Bauhus J, Khanna PK, Hopmans P, Weston C (2002) Is soil carbon a useful indicator of sustainable forest soil management? A case study from native Eucalypt forests of South-Eastern Australia. For Ecol Manag 171:59–74

Becker M, Johnson DE (2001) Cropping intensity effects on upland rice yield and sustainability in West Africa. Nutr Cycl Agroecosyst 59:107–117

Bond C (2002) The Cherokee nation and tribal uses of GIS. In: Craig WJ, Harris TM, Weiner O (eds) Community participation and Geographic Information Systems. Taylor and Francis, London, pp 283–293

Breman H, Kessler JJ (1995) Woody plants in agro-ecosystems of semi-arid regions. Springer, Berlin etc, 340pp

Brindza J, Holecyova J, Toth D (2007) In situ conservation and sustainable use of a native population of black mulberry (*Morus Nigra* L.) in Slovakia. Proceedings of the 2nd International Symposium on Plant Genetic Resources of Horticultural Crops, ISHS Acta Horticulturae 760, Leuven, pp 425–432

De Neergaard A, Magid J, Mertz O (2008) Soil erosion from shifting cultivation and other smallholder land use in Sarawak, Malaysia. Agric Ecosyst Environ 125:182–190

Ding GKC (2005) Developing a multicriteria approach for the measurement of sustainable performance. Build Res Info 33:3–16

Ewel JJ, Mazzarino MJ, Berish CW (1991) Tropical soil fertility changes under monocultures and successional communities of different structure. Ecol Appl 1:289–302

FAO (1987) On-farm maize drying and storage in the humid tropics. Agric Servs Bull 40. FAO, Rome, 60pp

Gepts P (2006) Plant genetic resources conservation and utilization: the accomplishments and future of a societal insurance policy. Crop Sci 46:2278–2292

Gobin A, Campling P, Feyen J (2002) Logistic modelling to derive agricultural land use determinants: a case study from southeastern Nigeria. Agric Ecosyst Environ 89:213–228

Gommes R, Fresco LO (1998) Everybody complains about climate. What can agricultural science and the CGIAR do about it? Paper Presented at the Mid-term Meeting of the Consultative Group for International Agricultural Research (CGIAR), FAO, Rome. http://www.fao.org/climatechange/media/15527/0/0/

Harris T, Weiner D (1998) Empowerment, marginalization, and "Community Integrated" GIS. Cartogr Geogr Info Syst 25:67–76

Harris T, Weiner D (2002) Implementing a community-integrated GIS: perspectives from South African fieldwork. In: Craig WJ, Harris TM, Weiner O (eds) Community participation and Geographic Information Systems. Taylor and Francis, London, pp 246–258

Kropff MJ, Bouma J, Jones JW (2001) Systems approaches for the design of sustainable agroecosystems. Agric Syst 70:369–93

Kwan Mei-Po (2000) Gender differences in space-time constraints. Area 31:145–156

Kyem PAK (2002) Promoting local community participation in forest management through a PPGIS application in southern Ghana. In: Craig WJ, Harris TM, Weiner O (eds) Community participation and Geographic Information Systems. Taylor and Francis, London, pp 218–231

Kyem PAK (2004) Of intractable conflicts and participatory GIS applications: the search for consensus amidst completing claims and institutional demands. Ann Assoc Am Geogr 94:37–57

Laituri M (2002) Ensuring access to GIS for marginal societies. In: Craig WJ, Harris TM, Weiner O (eds) Community participation and Geographic Information Systems. Taylor and Francis, London, pp 270–282

Lal R (1991) Soil structure and sustainability. J Sust Agric 14:67–92

Lal R (2008) Sustainable horticulture and resource management. Proceedings of the International Symposium on Sustainability Through Integrated and Organic Horticulture, ISHS Acta Hortic 760, Leuven, pp 19–43

Lavelle P (2000) Ecological challenges for soil science. Soil Sci 165:73–86

LEISA (1997) Fighting back with Integrated Pest Management. ILEIA Newslett 13(4):1–36

Maqsood I, Li JB, Huang GH, Huang YF (2005) Simulation-based risk assessment of contaminated sites under remediation scenarios, planning periods, and land-use patterns – a Canadian case study. Stoch Environ Res Risk Assess 19:146–157

Mbilinyi BP, Tumbo SD, Mahoo HF, Senkondo EM, Hatibu N (2005) Indigenous knowledge as decision support tool in rainwater harvesting. Phys Chem Earth 30:792–798

Mendham DS, O'connell AM, Grove TS (2002) Organic matter characteristics under native forest, long-term pasture, and recent conversion to Eucalyptus plantations in western Australia: Microbial biomass, soil respiration, and permanganate oxidation. Aust J Soil Res 40:859–872

Meredith TC, Gregory GY, Gisela F (2002) Mexican and Canadian case studies of community-based spatial information management for biodiversity conservation. In: Craig WJ, Harris TM, Weiner O (eds) Community participation and Geographic Information Systems. Taylor and Francis, London, pp 205–217

Miller DA, Hall MH, Voortman J, Kolb PJ (2002) A web-based decision support tool for forage species selection. Crop Management. http://www.plantmanagementnetwork.org/cm/element/sum.aspx?id=2211& photo=450

Mohamed MA, Ventura SJ (2000) Use of geomatics for mapping and documenting indigenous tenure systems. Soc Nat Resour 13:223–236

Muchow RC, Bellamy JA (eds) (1991) Climatic risk in crop production: models and management for the semi-arid tropics and subtropics. CAB International, Wallingford, 548pp

NRC (National Research Council) (1991) Toward sustainability. A plan for collaborative research on agriculture and natural resource management. Board on Science and Technology for International Development. National Academy Press, Washington DC, 33pp

Ong CK, Huxley PA (1996) Tree crop interactions: a physiological approach. CAB International, Wallingford; ICRAF, Nairobi, 386pp

Payton RW, Barr JJF, Martin A, Sillitoe P, Deckers JF, Gowing JW, Hatibu N, Naseem SB, Tenywa M, Zuberi MI (2003) Contrasting approaches to integrating indigenous knowledge about soils and scientific soil survey in East Africa and Bangladesh. Geoderma 111:355–386

Rainford C (2008) Soil health and productivity benefits of low-tillage organic systems: The common ground between organic and no-tilt farming practices. J Soil Water Conserv 63:19A–21A

Rijks D (1994) Agroclimatic characterization. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York, pp 241–244

Schmidt S, Lamble RE (2002) Nutrient dynamics in Queensland savannas: implications for the sustainability of land clearing for pasture production. Rangel J 24:96–111

Senanayake R (1991) Sustainable agriculture: definitions and parameters of measurement. J Sust Agric 14:7–28

Sieber R E (2002) Geographic Information Systems in the environmental movement. In: Craig WJ, Harris TM, Weiner O (eds) Community participation and Geographic Information Systems. Taylor and Francis, London, pp 153–172

Sims BG, Rodriguez F, Eid M, Espinoza T (1999) Biophysical aspects of vegetative soil and water conservation practices in the inter-Andean valleys of Bolivia. Mt Res Dev 19:282–291

Sivakumar MVK, Wallace JS, Renard C, Giroux C (eds) (1991) Soil water balance in the Sudano-Sahelian zone. IAHS Publication 199, Wallingford, 628pp

Sivakumar MVK, Zobisch MA, Koala S, Maukonen T (eds) (1998) Wind erosion in Africa and West Asia: problems and control strategies. ICARDA, Aleppo, 198pp

Sivakumar MVK, Gommes R, Baier W (2000) Agrometeorology and sustainable agriculture. Agric For Meteorol 103:11–26

Sombroek WS, Gommes R (1996) The climate change-agriculture conundrum. In: Bazzaz F, Sombroek W (eds) Global climate change and agricultural production. Direct and indirect effects of changing hydrological, pedological and plant physiological processes. FAO/Wiley, New York, pp 1–14

Stephens PR, Hewitt AE, Sparling GP, Gibb RG, Shepherd TG (2003) Assessing sustainability of land management using a risk identification model. Pedosph 13:41–48

Stigter CJ (1988) Microclimate management and manipulation in traditional farming. CAgM Report 25, WMO/TD 228, Geneva, 20pp + 6 App

Stigter CJ (1994) Management and manipulation of microclimate. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York and Oxford, pp 273–284

Stigter CJ, Weiss A (1986). In quest of tropical micrometeorology for on-farm weather advisories. Guest Editorial. Agric For Meteorol 36:289–296

Stigter CJ, Baldy, CM (1993) Manipulation of the microclimate by intercropping: making the best of services rendered. In: Sinoquet H, Cruz P (eds) Ecophysiology of tropical intercropping. INRA, Paris/Guadeloupe, pp 29–44

Stigter CJ (coord & ed), Karing PH, Stigter CJ, Chen W, Wilken GC (1992) Application of microclimate management and manipulation techniques in low external input agriculture. CAgM Report 43, WMO/TD 499, Geneva, 192pp

Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005). Using traditional methods and indigenous technologies for coping with climate variability. Clim Change 70:255–271

Stigter K, Baier W, Barrie I, Brunini O, Dommermuth H, Gat Z, Gommes R, Keane T, Chan Ah Kee, Lomas J, Milford J, Ravelo A, Rijks D, Samui RP, Walker S, Wang Shili, Weiss A (2010) General. Chapter 1 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Swindale LD (1988) Agricultural development and the environment: a point of view. Sustainable agricultural production: implications for international agricultural research. TAC, FAO, Rome, pp 7–14

Szott LT, Palm CA, Buresh RJ (1999) Ecosystem fertility and fallow function in the humid and subhumid tropics, Agrofor Syst 47:163–196

Teasdale JR (2007) Strategies for soil conservation in no-tillage and organic farming systems. J Soil Water Conserv 62:144A–147A

Thomas GW (1988) The ecological dimension: an assessment of the sustainability of dryland agriculture. In: Unger PW, Sneed TV, Jordan WR, Jensen R (eds) Challenges in dryland agriculture: A global perspective. Proceedings of the International Conference on Dryland Farming, Texas Agricultural Experimental Station, Amarillo/Bushland, Texas, 15–19 August, pp 27–32

Thomas RJ (2008) Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change. Agric Ecosyst Environ 126:36–45

Tulloch DL (2002) Environmental NGOs and community access to technology as a force for change. In: Craig WJ, Harris TM, Weiner O (eds) Community participation and Geographic Information Systems. Taylor and Francis, London, pp 192–204

Van Calker KJ, Berentsen PBM, Giesen GWJ, Huirne RBM (2008) Maximising sustainability of Dutch dairy farming systems for different stakeholders: a modelling approach. Ecol Econ 65:407–419

Walker DH, Leitch AM, Lai R, Cottrell A, Johnson AKL, Pullar D (2002) A community-based and collaborative GIS joint venture in rural Australia. In: Craig WJ, Harris TM, Weiner O (eds) Community participation and Geographic Information Systems. Taylor and Francis, London, pp 137–152
Weiner D, Harris TM (2003) Community-integrated GIS for land reform in South Africa. J Urban Reg Info Syst Assoc 15(2):61–73
Wheeler SA (2008) What influences agricultural professionals' views towards organic agriculture? Ecol Econ 65:145–154
Wiener JG, Naimo TJ, Korschgen CE, Dahlgren R, Sauer J, Lubinski K, Rogers S, Brewer S (1995). Biota of the upper Mississippi River ecosystem. In: LaRoe ET, Farris GS, Puckett CE, Doran PD, Mac MJ (eds) Our living resources: a report to the nation on the distribution, abundance, and health of US plants, animals, and ecosystems, US Department of the Interior, National Biological Service Report, Washington, pp 236–239
Williams JD (2008) Soil erosion from dryland winter wheat-fallow in a long-term residue and nutrient management experiment in North-Central Oregon. J Soil Water Conserv 63:53–59
Zobeck TM, Crownover J, Dollar M, Van Pett RS, Acosta-Martinez V, Bronson KF, Upchurch DR (2007) Investigation of soil conditioning index values for southern High Plains agroecosysterns J Soil Water Conserv 62:433–442
Zurayk R, El-Awar F, Hamadeh S, Talhouk S, Sayegh C, Chehab AG, Al Shab K (2001) Using indigenous knowledge in land use investigations: a participatory study in a semi-arid mountainous region of Lebanon. Agric Ecosyst Environ 86:247–262

III.2.2.(iii) Detection and Awareness of Increasing Climate Variability and the Elevating Climate Risk: Monocropping

Kees Stigter

To boost awareness on increasing climate variability and the elevating climate risk in agricultural production (and other uses of natural resources), most recently the new IPCC reports (WMO/UNEP 2007; RealClimate 2007) and the work of Gore (2006) have scored very high. Detection of increasing climate variability is a matter of science (e.g. NOAA 2007; WMO 2007). Awareness of elevating risks is a matter of extension (CPAS 2004; Hansen and Sivakumar 2006; Stigter 2006a; UNFCCC 2007).

Cases of detected increased climate variability going hand in hand with extremer events (showing the elevating climate risk) with impact on agricultural production have been reported for hurricanes in the north Atlantic since 1970, while there are also suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater (World Climate Report 2007). More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and sub-tropics. Increased drying linked with higher temperatures and decreased precipitation have contributed to changes in drought, while the frequency of heavy precipitation events increased over most land areas (IPCC 2007). This explains why droughts and floods can be more frequent and/or more intense in the same areas (Dhameja 2001) and how forecasted climate change can contain longer sequences of dry and wet years (Abdalla et al. 2002).

Dhameja's (2001) paper, however, also draws attention to the relevance of the development-disaster interconnection as a lost awareness and the dying traditional flood controls and rainwater harvesting techniques (see also Stigter et al. 2005, 2007). Stigter (2007), answering the question in relation to agrometeorology whether development can be sustainable when the climate is not sustainable, argued that once response farming is aimed at as an awareness approach (Stigter et al. 2007), this remains the same approach under whatever climate change is taking place, but to more varying conditions. Principles, organization, role of research and

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_16,

communication infrastructure, education and extension approaches etc. will not differ, but may be complicated by change (Stigter 2007). See also Box III.2.14.

Box III.2.14

In 1995 the government of Ethiopia launched a “Policy on Disaster Prevention, Preparedness and Mitigation”, making a shift in strategy from pure relief provision to reduction of drought impact. It is now called the Disaster Prevention and Preparedness Agency (Helmuth et al. 2007). Rathore and Stigter (2007) are of the opinion that challenges to disaster risk mainstreaming, in terms of adaptation strategies, and to mitigation practices, in terms of impact reductions, always need to be dealt with for such drought events. Challenges to contingency planning and responses and to basic preparedness as coping strategies bear much similarity for various disasters.

The key challenge is in the combination of these strategies and in facing a combination of challenges to each of them. The emergency relief response mechanism requires planners to identify disasters and their probability, evolve signal/warning mechanisms, identify the activities and sub-activities, define the level of response, specify authorities, determine the response kind, work out individual activity plans, have quicker response teams, undergo preparedness drills, provide appropriate delegations and have alternative plans. This has to be organized identically but must have different contents for each type of disaster. Other preparedness approaches should reduce emergency relief necessities as much as possible (Rathore and Stigter 2007).

The forecast for the short rainy season in Ethiopia in 2002 was a high probability of normal rainfall in the crop-growing regions. But as the season progressed, it became clear that this would not materialize. Rainfall in February was far below normal: in March it improved, but in April and May it was again below normal (Hellmuth et al. 2007). Regular monitoring under an early warning system began to indicate problems with the short-season crops. A rapid assessment in June confirmed a bleak outlook. The harvest of short-season crops was very ppor, long-cycle crops were severely compromised, and a serious food shortage was looking likely for 2003. Around this time, it was confirmed that an El-Nino event was occurring, with its associatd impacts on global climate.

In Ethiopia this was known to be associated with lower rainfall in the long rainy season. Forecasts were therefore for the drought to intensify. Based on these assessments, an appeal was made in September 2002 for external aid. Food shortages reached their peak in April 2003, but the prompt response of the government had paid off (Helmuth et al. 2007). However, vulnerabilities to hazards can be seriously reduced by temporary or permanent measures leading to impact reduction (Rathore and Stigter 2007). Agrometeorology in Ethiopia, that used to be rather client oriented (Stigter 2006b), should be structurally overhauled and supported to play a role in designing such measures. Designing agrometeorological services should become a priority in capacity building (KNMI 2009).

References

Abdalla AT, Stigter CJ, Bakheit NI, Gough MC, Mohamed HA, Mohammed AE, Ahmed MA (2002) Traditional underground grain storage in clay soils in Sudan improved by recent innovations. Tropicultura 20:170–175

CPAS (2004) Climate Prediction Applications Science Workshop. http://climateservices.coaps.fsu.edu/alpabstracts.doc

Dhameja A (2001) Droughts and floods: a case for "dying wisdom". In: Sahni P, Dhameja A, Medury U, (eds) Disaster mitigation, experiences and reflections. Prentice/Hall of India, New Delhi, pp 76–91

Gore A (2006) An inconvenient truth. http://www.climatecrisis.net/

Hansen JW, Sivakumar MVK (eds) (2006) Advances in applying climate prediction to agriculture. Clim Res 33:1–122

Hellmuth ME, Moorhead A, Thomson MC, Williams J (eds) (2007) Climate risk management in Africa: learning from practice. International Research Institute for Climate and Society (IRI), Columbia University, New York, 115 pp. http://www.fanrpan.org/documents/d00255/1-Climate-risk_Africa_2007.pdf

IPCC (2007) Climate change 2007: the physical science base. Summary for policy makers. http://www.ipcc.ch/SPM2feb07.pdf

KNMI (for Netherlands Government, compiled by Kees Stigter, second update, 2009) Capacity building in the area of agrometeorological services through roving seminars. Document originally distributed and presented as CAgM-XIV/INF. 4 at the XIVth Session of the WMO CAgM, New Delhi, October/November 2006, 13pp

NOAA (2007) Observing climate variability and change. http://www.oar.noaa.gov/climate/t_observing.html

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties-Regional Perspectives: Asia. In: Sivakumar MVK, Motha R (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 53–69

RealClimate (2007) Climate science from climate scientists. http://www.realclimate.org/index.php/archives/2007/05/start-here/

Stigter K (2006a) A contemporary history of a new approach to applied agrometeorology. http://www.agrometeorology.org/index.php?id=589

Stigter K (2006b) Agrometeorological services in various parts of the world, under conditions of a changing climate. Austin Bourke Memorial Lecture presented in the Royal Irish Academy, Dublin, in the evening of 2 March. Extended Abstract available on the INSAM website under "Accounts of Operational Agrometeorology".

Stigter K (2007) Agrometeorological services to prepare farmers for climate extremes and climate use. Paper Presented Under "Agrometeorology and Sustainable Development" at the XVth Congress of the Brazilian Society for Agrometeorology, Aracaju, July. Rev Brasil Agrometeorol 15:202–207

Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005) Using traditional methods and indigenous technologies for coping with climate variability. Clim Change 70:255–271

Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi YM (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 171–190

UNFCCC (2007) Assessing, predicting and managing current and future climate variability and extreme events, and implications for sustainable development. Background paper. svrweb01.unfccc.int/files/adaptation/sbsta_agenda_item_adaptation/application/pdf
WMO/UNEP (2007) Intergovernmental Panel on Climate Change. http://www.ipcc.ch/
WMO (2007) Climate. http://www.wmo.ch/pages/themes/climate/index_en.html
World Climate Report (2007) Lessons from a 5,000 year Hurricane Record. http://www.worldclimatereport.com/

III.2.2.(iv) (Changes in) Adaptation Strategies to Climate Changes: Monocropping

Kees Stigter

A very serious issue in all matters related to climate change is to increase understanding on adaptation strategies to climate changes. For agrometeorological applications as well as in general, Salinger et al. (2000) already stated that the agricultural sector has two obligations.

The first is to be better prepared to react to the (increasing) variabilities and extremes, and prepare scenarios for possible lasting change (in general e.g. NEF 2004; Srinivasan 2004; CEEPA 2007; Oxfam 2007; Wisner et al. 2007; Yohe 2007 and for agricultural meteorology e.g. Stigter et al. 2000; WMO 2003; Perarnaud et al. 2005; Sivakumar et al. 2005; Stigter et al. 2005; Holden et al. 2009). See also Box III.2.15. Quite some of the contents of the more general references apply to developing societies with strong rural and food security components.

The character of this need to adapt is determined initially by worsening limiting factors of agricultural production and the vulnerability of farming systems (Salinger et al. 2000) to which some new windows of opportunity may be added (e.g. Stigter 2007). An example from China is on "Winter straw mulching increasing water use efficiency and yields in winter wheat" (Stigter et al. 2008b). By comparison with winter wheat with uncovered soil, it was shown that the soil water content of winter wheat mulched with corn straw was much better, especially before the wheat elongating stage in spring. In spring, soil temperature was for example from 0.1 till 0.7 °C lower at 20 cm depth under mulch.

Looking at the energy balance, mulching caused an increase of sensible heat flux and a decrease of latent heat flux, so the soil evaporation from mulched wheat fields was reduced and the transpiration of wheat was increased after the elongation stage. Wheat yields under mulching increased by 5%, but more importantly the water use efficiency increased with 12–16% under an initial irrigation and subsequently rainfed conditions afterwards (Stigter et al. 2008b). This is a splendid adaptation to present needs of larger water scarcity. This example as an agrometeorological service is further detailed in Sect. II.C.IX.

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_17,

Box III.2.15

Whether an existing agrometeorological service is automatically adapted to climate change or whether the adaptation strategy needs a change depends very much on the contents of the strategy. In Cuba, the "SAT" agrometeorological service of drought forecasting and early warning became operational in the Camaguey provincial weather service in November 1994, just in time to predict in September 1995 the 1995–1996 winter-drought disaster, which brought the government to declaring "drought emergence". This drought became known as the "Camaguey cattle emergence" and established the relevance of "SAT", of which improved versions are now available. Users are governmental authorities, end users in the agricultural and insurance sectors. Governmental institutions rely very heavily on the existence of this agrometeorological service. It has been fundamental in all adaptation measures and actions taken to relieve the negative impacts of drought in Camaguey, including saving nearly 100,000 heads of cattle and the maintenance of milk production levels (Stigter 2006; WMO 2010). This is one of the examples for which protocol forms were filled as published in Part II of this book and this was a first prize winner in 2005. See Sect. II.19. Climate change adaptation is typically built in within this agrometeorological service and it may be noted in a difference in frequency of emergency situations over the years.

The agrometeorological service of an "Advisory and service system of crop and variety planning in Xing'anmeng, Inner Mongolia" as described by Stigter et al. (2008a) is based on the fact that the Sub-Province has roughly a 1,000 m difference between places where crops are grown and, together with latitude and slope, this makes thermal time the most important factor governing the performance of crops under the availability of sufficient soil moisture. Details may be found in section II.C.I. Within the Sub-Province, county wise storage of data for each crop shows maps of varieties very suitable, suitable and non-suitable in villages of the Sub-Province, based on the data of the model. The model is regularly updated with new agronomic information. It works with 30 years (1970–2000) climatological normals, but is in the process of adapting to meteorological data of the past decade. This is typically necessary to be able to adapt to climate changes that might have occurred and that will influence the suitability criteria of the regions distinguished. It is clear in this context of climate change that updated and quality controlled reliable meteorological and agronomical data are the crux of the matter in addition to the given geographical conditions of agricultural fields/plots (Stigter et al. 2008a).

The second obligation of the agricultural sector is to react to demands of reducing its contributions to possible global warming, which asks for changes in production methods (e.g. Desjardins et al., 2005, 2007), but for the poorer sectors in these countries these should be limited to win-win situations (Salinger et al., 2000). See also Chaps. IV.14, IV.15 and IV.16.

References

CEEPA (2007) Climate change and agriculture in Africa. http://www.ceepa.co.za/Climate_Change/index.html

Desjardins RL, Smith W, Grant B, Campbell C, Riznek R (2005) Management strategies to sequester carbon in agricultural soils and to mitigate greenhouse gas emissions. Clim Change 70:283–297

Desjardins RL, Sivakumar MVK, de Kimpe C (eds) (2007) The contribution of agriculture to the state of climate. Agric For Meteorol 142:87–324

Holden NM, Sweeney J, Fealy R (2009). Effects of climate change on agriculture. In: Guide to Agricultural Meteorological Practices, WMO 134, 3rd edn, Geneva, in print. http://www.agrometeorology.org/fileadmin/insam/repository/gamp_chapt17.pdf

NEF (2004) Up in smoke? Threats from, and responses to, the impact of global warming on human development. New Economics Foundation. http://www.neweconomics.org/gen/news_upinsmoke.aspx

Oxfam (2007) Adapting to climate change. What's needed in poor countries, and who should pay. Oxfam briefing paper 104. http://www.oxfam.org.uk/what_we_do/issues/climate_change/downloads/bp104_adapting_to_climate_change.pdf

Perarnaud V, Seguin B, Malezieux E, Deque M, Loustau D (2005) Agrometeorological Research and applications needed to prepare agriculture and forestry for 21st century climate change. Clim Change 70:319–340

Salinger JJ, Stigter CJ, Das, HP (2000) Agrometeorological adaptation strategies to increasing climate variability and climate change. Agric For Meteorol 103:167–184

Sivakumar MVK, Motha RP, Das HP (eds) (2005) Natural disasters and extreme events in agriculture: impacts and mitigation. Springer, Heidelberg/Berlin/New York

Srinivasan A (2004) Local knowledge for facilitating adaptation to climate change in Asia and the Pacific: policy implications. IGES-CP Working Paper 2004-002. http://www.iges.or.jp/en/cp/pdf/report8.pdf

Stigter K (2006) Agrometeorological services in various parts of the world, under conditions of a changing climate. Austin Bourke Memorial Lecture presented in the Royal Irish Academy, Dublin, in the evening of 2 March. Extended Abstract available on the INSAM website under "Accounts of Operational Agrometeorology"

Stigter K (2007) Agrometeorological services to prepare farmers for climate extremes and climate use. Invited Paper Presented Under "Agrometeorology and Sustainable Development" at the XVth Congress of the Brazilian Society for Agrometeorology, Aracaju, July. Rev Brasil Agrometeor 15:202–207

Stigter CJ, Sivakumar MVK, Rijks DA (2000) Agrometeorology in the 21st Century: workshop summary and recommendations on needs and perspectives. Agric For Meteorol 103:209–227

Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005) Using traditional methods and indigenous technologies for coping with climate variability. Clim Change 70:255–271

Stigter K, Niu Baoliang, Yang Song, Hou Qiong, Zheng Dawei, Ma Yuping, Wang Shili (2008a) Recent identification of two agrometeorological services in Inner Mongolia Autonomous Region, Northern China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology"

Stigter K, Li Chunqiang, Zheng Dawei, Wang Shili, Ma Yuping (2008b). Further identification of two agrometeorological services in Hebei Province, China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology"

Wisner B, Fordham M, Kelman I, Johnston BR, Simon D, Lavell A, Brauch HG, Spring UO, Wilches-Chaux G, Moench M, Weiner D (2007) Climate change and human security. http://www.radixonline.org/cchs.html

WMO (2003) Agrometeorology related to extreme events (by Das HP, Adamenko TI, Anaman KA, Gommes RG, Johnson G.). Technical Note 201, WMO 943, Geneva, 137pp

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by Stigter CJ. WMO, Geneva, in print

Yohe G (2007) A roadmap for implementing adaptation policy. Tiempo Climate Newswatch (22–29/7). http://www.cru.uea.ac.uk/tiempo/newswatch/comment070417.htm

III.2.3 Coping with Extreme Meteorological Events

III.2.3.(A) Problems and Solutions in Coping with Extreme Meteorological Events in Agricultural Production, and Challenges Remaining for the Use of Science to Contribute to Problem Analyses and Designing Valuable Solutions in this Context: Monocropping

Kees Stigter

In first instance it will be the agrometeorologist's task here to develop understanding on the phenomena, impacts, actions, problems, solutions and policies related to priority extreme meteorological events that cause farmers and their local governments the largest difficulties in monocropping in a region. In applied agrometeorology we must consider the causes of these phenomena known, as far as the basic sciences were able to explain their occurrence in the region. The scales of these phenomena are of utmost importance (UNEP 2003–2007).

Seemann et al. (1979), in that part of their book that deals with "Applied Agrometeorology", have only less than half a superficial page on drought without any references (Chirkov 1979). Geiger et al. (1995) have the word "drought" not in their index because they have a scientific outlook and they deal with the small scale impacts. Glantz (1987) was the first to propose to get away from considering climate conditions as drought as a boundary condition and to consider climatic factors only in the context of development constraints. Reijntjes et al. (1992) with a phenomenological approach and a larger scale outlook particularly deal for example with case studies of adaptive responses to drought. These suggest that farmers' crop experiments in Africa and India increase in number and complexity after drought crises but also indicate that farmers under harsh LEIA conditions must largely accept environmental constraints as drought and are for example in need of crops well adapted to these conditions. Agrometeorological science has to support these impact related concerns (see also Part I).

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_18,

Another aspect of this is the changing risk aversion strategies of farmers. Governments and development projects have encouraged high-input, high-risk strategies, for example, planting hybrid maize instead of sorghum and millet. Thus the effects of the prolonged drought of the early 1990s in eastern and southern Africa was undoubtedly exacerbated by the near-monocropping of maize rather than spreading the risks across a range of crops with greater tolerance of low-rainfall regimes (Blench and Marriage 1998).

Rathore and Stigter (2007) distinguish five types of relatively short-term extreme events: (i) high intensity rainfall and floods, (ii) tropical storms, tornadoes and strong winds, (iii) extreme temperatures including heat waves and cold waves, (iv) droughts and (v) wildfires and bushfires. The last subject is not related to any extreme meteorological events as far as monocropping is concerned. As to droughts, coping with possible long term drought in advance and mitigation of and for dry spells are the approaches found (Rathore and Stigter 2007). For the first action, the guide by Knutsen et al. (1998) is still an excellent approach with educational merits. Quite a complete mitigation action plan for a developing country may be found in Pomee et al. (2005) for the second action needs.

Although due to overwhelming effects of other extreme meteorological events, impacts of extreme temperatures were until recently no considerations in development action planning for agriculture in developing countries, higher (minimum) temperatures were observed to become detrimental for some crop yields, particularly rice (Rathore and Stigter 2007; UNEP 2007). An excellent report, also for educational purposes, covering actions to reduce vulnerabilities of agriculture to impacts of strong winds and floods as storm-related disasters came from FAO (2001a) and includes impacts on production potential of land and coping strategies for various types of land use in agriculture. Monocropping often needs protection from strong winds and their consequences with agroforestry interventions (Stigter et al. 2002).

Obvious surface and sub-surface drainage apart (Stigter et al. 2003), on-farm storage of water in lowland and flat upland rice fields was until recently the only example we found of a solution of coping with floods in monocropping (Gomez 2005). The case study in Box III.2.16 reported more recently by Helmuth et al. (2007) looks at how Mozambique prepares for and deals with flood events. Floods caused by high rainfall cause soil erosion, but it is now generally accepted that also this is not simply a technical problem. The reason for a low success rate lies not only in the failure to solve certain technical aspects of the problem to full satisfaction, but also in the need to pay more attention to the social and economic roots of erosion crises (e.g. Roose 1996; Kinama et al. 2007).

Solutions to monocropping problems due to extreme events are therefore to be found in a combination of agrometeorology with an understanding of the livelihood of farmers in which the agrometeorology has to be applied. This is where policy designs and policy preparations come into the picture (e.g. Baier 2004). It is exactly this approach that WMO/CAgM has tried to promote in the last two decades by increasing the involvement of developing countries (Sivakumar et al. 2000; WMO

Box III.2.16

A case study reported on by Helmuth et al. (2007) looks at how Mozambique prepares for and deals with flood events, drawing on experience in 2000, when the most severe floods in living memory affected large areas of the country. It examines what climate information was available, and how it was used, before and during the disaster. It then reflects on the 2000 floods, and in particular on the best practice elements of the country's strategies.

A Department for Combating Natural Disasters was already established in 1977 but new policies were passed in 1999, in which there was a change from reaction to preparedness for floods that is facilitated by a flood early warning system. This provides forecasts of flood risks, detects and monitors flooding, and puts out flood warnings when necessary, paving the way for a coordinated response. The National Institute of Meteorology (NIM), part of the NMHS of Mozambique, collects meteorological data and prepares a range of forecasts: seasonal, 4-days and daily. It is also responsible for monitoring cyclones. Ahead of the rainy season, in October, the seasonal forecast informs a meeting of water resources experts, that assess preparedness for the predicted weather. If flooding is expected, a flood team is mobilized. Regional Water Administrations (RWAs), another part of the NMHS, work at the river basin level, monitoring water levels and providing data to NIM that also collects data from stations across the country, from radar equipment, and from satellites, periodically updating the forecasts. The RWAs issue flood warnings to district governments and local authorities and also to all media.

But Mozambique cannot address its water-related climate challenges alone, since weather events outside the country often largely determine the internal situation. Regional cooperation is therefore critical, particularly for flood prediction. This is facilitated by SARCOF, the Southern Africa Regional Climate Outlook Forum of the Southern African Development Community (SADC). The SARCOF meeting of September 1999 warned for certain probabilities, but it was not alarming. NIM was not happy with this. In the previous year its scientists had noted a correlation between La Nina activity and high rainfall in southern Mozambique, conditions which now appeared repeating themselves even more forcefully. They also thought to have noted that 1999–2000 coincided with the cyclic peak of sunspot activities, which had, over the past 100 years, correlated with periods of exceptionally heavy rainfall. On this basis NIM raised the probability of above-average rainfall to 50% and warned that there was a high probability of floods. This was a brave move since, two seasons before, a drought had been predicted which had not materialized, putting NMI's credibility in question.

It is uncertain whether the mass media were aware of the flood prediction. Links between the media and the weather services were weak or non-existent. There was certainly no media coverage of the risk during the months and weeks immediately before the floods. However, the warnings themselves proved to be fully justified when, between January and March 2001, the worst floods in over 100 years affected three major river basins. Much reflection and analysis was done after the floods (Wiles et al. 2005) and as a result some improvements have been made to the flood early warning system and the practices how to cope with floods. A number of scientific advances may benefit flood early warning in the future. These include improved capacity for predicting tropical cyclones. Making sure that people receive early warnings at the right time, understand them, and have the capacity to act on them appropriately remains a substantial challenge, shared by the media and the authorities (Helmuth et al. 2007).

2006). The same applies for example to FAO and UNEP (e.g. UNEP 2000). In the selected literature below, policy matters occur almost without exception. One may talk about a policy divide, characterized by two distinct dimensions involving policy development and implementation with some regions having strength in both and others still struggling in both (UNEP 2003). Without solving this divide, also in agrometeorology of monocropping, livelihood of farmers will not improve (e.g. Stigter 2006).

Attempts to improve this situation with a farming and farmer livelihood focused approach of coping with extreme meteorological events were summarized for floods by FAO (2001b), for cyclonic winds in Sahni et al. (2001), for extreme particular events by Gommes and Nègre (1992) and for drought by Gathara et al. (2006). The remaining challenges for agrometeorological science are that many more agrometeorological services should be derived, established and applied within and from such approaches (Stigter 2004). Smith (1975) was already of the opinion that when a warning can be given and time and techniques are available to reduce the adverse effects, then the basic requirements of a valuable form of applied science have been met. This is confirmed in the above. Concentration of the efforts of agrometeorologists in this type of activity can result in gains in primary production out of all proportions to the cost of research and subsequent services (Smith 1975).

References

Baier W (Coord) (2004) Case studies of economically beneficial agrometeorological applications and services and other success stories in agrometeorology for policy matters. Final Report of the CAgM Expert Team, WMO/TD No. 1202, Geneva, 79pp

Blench R, Marriage Z (1998) Climatic uncertainty and natural resource policy: what should the role of government be? Natural Resources Perspectives 31. ODI, London, 4pp

Chirkov YI (1979) Droughts, dry winds, dust storms and hail. In: Seemann J, Chrirkov YI, Lomas J, Primault B (eds) Agrometeorology. Springer, Berlin/Heidelberg/New York, pp 212–216

FAO (2001a) Reducing agricultural vulnerability to storm-related disasters. FAO Committee on Agriculture/01/6. http://www.fao.org/docrep/meeting/003/x9178e.htm

FAO (2001b) Reducing agricultural vulnerability to storms, with special reference to farming systems and methods. Report of the FAO Asia-Pacific Conference on Early Warning, Prevention, Preparedness and Management of Disasters in Food and Agriculture, Chiangmai, RAP 2001/14, Annex XI, APDC 01/07. http://www.fao.org/DOCREP/005/AC120E/AC120e12.htm

Gathara ST, Gringof LG, Mersha E, Sinha Ray KC, Spasov P (2006). Impacts of desertification and drought and other extreme meteorological events. CAgM Report 101, WMO/TD 1343, Geneva, 85pp

Geiger R, Aron RH, Todhunter P (1995) The climate near the ground, 5th edn. Vieweg, Braunschweig, 528pp

Glantz MH (ed) (1987) Drought and hunger in Africa: denying famine a future. Cambridge University Press, Cambridge etc., 457pp

Gomez B (2005) Degradation of vegetation and agricultural productivity due to natural disasters and land use strategies to mitigate their impacts on agriculture, rangelands and forestry. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg/New York, pp 259–276

Gommes R., Nègre T (1992) The role of agrometeorology in the alleviation of natural disasters. Agrometeorology Series Working paper No 2. FAO, Rome, 22pp

Hellmuth ME, Moorhead A, Thomson MC, Williams J (eds) (2007). Climate risk management in Africa: learning from practice. International Research Institute for Climate and Society (IRI), Columbia University, New York, 115pp. http://www.fanrpan.org/documents/d00255/1-Climate-risk_Africa_2007.pdf

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2007) Contour hedgerows and grass strips for erosion and runoff control in semi-arid Kenya. Arid Land Res Manag 21:1–19

Knutsen C, Hayes M, Phillips T (1998) How to reduce drought risks. Western Drought Coordination Council. http://drought.nl.edu/plan/handbook/risk.pdf

Pomee MS, Zaheer-ul-Ikram, Khan MA, Ali I (2005) Drought mitigation measures: an overview under Pakistan's perspective. Pakistan Water Resour 9(2):31–42. See also www.pcrwr.gov.pk/New-Journals/jodwm.htm

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties in Asian regions. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 53–69

Reijntjes C, Haverkort B, Waters-Bayer W (1992) Farming for the future. An introduction to low-external-input and sustainable agriculture. Macmillan/ILEIA, London/Leusden, 250pp

Roose E (1996) Land husbandry – components and strategy. FAO Soils Bull 70. FAO, Rome. http://www.fao.org./docrep/T1765E/t1765e1a.htm

Sahni P, Dhameja A, Medury U (eds) (2001) Disaster mitigation: experiences and reflections. Prentice-Hall of India, New Delhi, 214pp

Seemann J, Chrirkov YI, Lomas J, Primault B (eds) (1979) Agrometeorology. Springer, Berlin etc, 324pp

Sivakumar MVK, Stigter CJ, Rijks DA, Obasi GP (2000) "Foreword" by the guest editors and "Preface". In: Sivakumar MJ, Stigter CJ, Rijks DA (eds) Agrometeorology in the 21st Century – Needs and Perspectives. Agric For Meteorol 103:1–4

Smith LP (1975) Methods in agricultural meteorology. Elsevier, Amsterdam, 210pp

Stigter CJ (2004) The establishment of needs for climate forecasts and other agromet information for agriculture by local, national and regional decision-makers and users communities. In: Applications of climate forecasts for agriculture. Proceedings of the RA I (Africa) Expert Group Meeting in Banjul, the Gambia (December 2002). AGM-7/WCAC-1, WMO/TD1223, Geneva, pp 73–86

Stigter K (2006) Scientific research in Africa in the 21st century, in need of a change of approach. Afr J Agric Res 1:4–8

Stigter CJ, Mohammed AE, Al-amin NKN, Onyewotu LOZ, Oteng'i SBB, Kainkwa RMR (2002) Agroforestry solutions to some African wind problems. J Wind Eng Ind Aerodyn 90:1101–1114

Stigter CJ, Das HP, Murthy VRK (2003) Beyond climate forecasting of flood disasters. Invited Lecture on the Opening Day of the Fifth Regional Training Course on Flood Risk Management (FRM-5) of the Asian Disaster Preparedness Center (Bangkok) and the China Research Center on Flood and Drought Disaster Reduction (Beijing), Beijing, September. Available from ADPC (Bangkok) on CD-ROM. Also available at http://www.agrometeorology.org/fileadmin/insam/repository/ADPC2mp.pdf

UNEP (2000) Managing fragile ecosystems: combating desertification and drought. Agenda 21, Chapter 12. UNEP, Nairobi. www.unep.org/Documents

UNEP (2003) State of the environment and policy retrospective: 1972–2002: Disasters. UNEP, Nairobi, pp. 270–300. www.unep.org/geo/geo3/english/pdfs/chapter2-9_disasters.pdf

UNEP (2003–2007) Geo year books. UNEP, Nairobi, Kenya. www.unep.org/Documents

UNEP (2007) Millions at risk of hunger and water stress in Asia unless global greenhouse emissions cut. Asian governments need to mainstream "Climate Proofing" into national development strategies. UNEP Press Releases, April. UNEP, Nairobi. http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=504& ArticleID=5551& l=en& t=long

Wiles P, Selvester K, Fidalgo L (2005) Learning lessons from disaster recovery: the case of Mozambique. World Bank, Washington, DC. http://siteresources.worldbank.org/INTDISMGMT/Resources/mozambique.pdf

WMO (2006) Commission for Agricultural Meteorology (CAgM). The first fifty years. WMO-No. 999, Geneva, 44pp

III.2.3.(B) Designing and Selecting Efficient Early Warning Strategies and Increasing Their Efficiencies in Monocropping

H.P. Das

Monocropping often needs protection from weather and climate hazards. A sufficiently early and reliable signal of impending adverse conditions could permit actions on the part of the planners and decision makers to devise weather related coping strategies and thus palliate the negative environmental impacts of a poor agricultural season. Farmers have to be ready to adapt to the range and frequency of shocks that extreme meteorological events bring and they have to be made able to apply the available technical knowledge and information to develop their coping strategies (e.g. Rathore and Stigter 2007). Since 1989, the National Agricultural Drought Assessment and Monitoring System (NADAMS) in India has been providing biweekly drought bulletins which describe prevalence, relative severity level, and persistence through the crop growing season (Box III.2.17).

Box III.2.17

The India Meteorological Department monitors drought among others by computing an index known as the Aridity Index using a water balance technique (Das 2000). Geographical Information Systems (GIS) are used to map these indices, in order to monitor their behavior and provide information about areas experiencing drought and drought severity. The availability of reliable seasonal drought forecasts should vastly extend the scope of response farming, allowing development of a limited range of different agronomic packages; in any particular year, the most appropriate extension packages could be promoted in accordance with the actual forecast for the area (Williams 2000). In some areas, particularly in the countries of the south pacific regions, an important tool to predict seasonal drought is EL Nino Southern Oscillation (ENSO). The link with ENSO can be formalized by calculating

H.P. Das (✉)
Retired from Indian Meteorologidal Department, Pune, India
e-mail: hpd_ag@rediffmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_19,

precipitation probability distributions conditional on the status of ENSO (Ropelewski 1995).

Satellite sensors are capable of discerning many changes through spectral radiance measures and manipulation of such measures into vegetation indices that are sensitive to the rate of plant growth as well as to the amount of growth (Curran 1985). Such indices are also sensitive to the changes in vegetation affected by moisture stress. India has developed a space-based strategy for all the three phases of drought management, namely the preparedness phase, the prevention phase and the relief phase. Since 1989, the National Agricultural Drought Assessment and Monitoring System (NADAMS) has been providing biweekly drought bulletins which describe prevalence, relative severity level, and persistence through the crop growing season. The interpretation takes into account rainfall and aridity anomaly trends (Das 2005b).

Extreme events do less damage when they strike a resilient well prepared community (Stigter et al. 2003). It is therefore possible to mitigate their impacts with an early detection and warning. It is important to design approaches for efficient early warning strategies. Timely information is essential. In industrialized countries and economically advanced farmers in under-industrialized countries, internet represents one fast way to disseminate agrometeorological information to the end-users in a timely manner. Stigter (2007, 2008, 2009) emphasized the importance of agrometeorological services to prepare farmers for climate extremes to minimize their adverse effects on crop production.

The WMO GTS provides the backbone of the telecommunications for the relay of warnings, forecasts, observational data and related information within the meteorological community as well as to some major external users and, in some instances, supports early warning for non-weather hazards (Nunez 2005). However, some other communication systems are more appropriate for distributing warnings to the local population and external agencies, particularly when speed is essential. In general, the effective dissemination of warnings to the public and lower level administrators requires communication systems which have a very broad public reach, such as radio and television and community warning facilities. The dissemination of warnings through these external agents and facilities is, however, carefully coordinated to ensure timeliness and accuracy and, as noted elsewhere, experience confirms that there must be a single official issuing authority for warnings to minimize confusion.

Worldwide, floods have the greatest damage potential, particularly in the agricultural sector of developing countries. Damages caused by floods have been increasing in the recent past, mainly as a consequence of the expansion of settlements and the growth of investments in flood plains. If the risk of flooding is assessed, and the use of flood plains is well managed, losses can be reduced significantly. Many lives can also be saved provided adequate warnings of floods are given to those under threat.

In forecasting the progress of an extreme flood event that is already happening, the crucial factor is the determination of the future development of precipitation, together with predicting the progress of the system in question. For this purpose, stochastic precipitation forecasts, as well as radar and satellite-derived fields of estimated precipitation for large scale observations may be applied (Das 2005a). A flood-forecast system has to work operationally (i.e., present information on the state of the river basin will be transferred on-line to the run-off model, thus providing the basis for a continuously updated forecast). For some regions such a runoff-forecast system already exists. As a measure for reducing damage potential, these systems should be combined with warning systems, which are aimed at launching response activities and starting already developed scenarios for action in case of disaster.

Among all extreme meteorological events, those caused by Tropical Cyclones (TCs) are always the worst, both in terms of death toll and economic losses, including damages in the agricultural sector. There has been a vast improvement in forecasting techniques and cyclone warning services in recent years. Pattern recognition techniques are used not only for forecasting the movement of TCs, but also for forecasting their other attributes such as strong winds and heavy rains. Satellite and radar images too go a long way in meeting these requirements. A warning system for TCs operates under three functional headings: environmental monitoring, the preparation of forecasts and warnings and finally the dissemination of forecasts and warnings. These three functional areas are highly interdependent and must be fully coordinated. The objectives of the warning system may be summarized as the provision of timely and accurate warning of TCs in order to contribute to the protection of lives and property, to the mitigation of human suffering and minimalization of economic losses, including crop damages.

Although TC motion forecasts have improved over the years, the intensity forecasts have still a lot to be achieved. Using the frequently (hourly to half-hourly) available satellite imagery, a lot of experience has been gathered in the analysis of tropical storm intensity. Since the launch of modern satellites, the intensity of cyclones has been well-captured. This has enabled cyclone experts to issue realistic storm surge forecasts. However, our knowledge of structural changes in tropical storms on account of storm/land interaction is still in its infancy. The development of localized zones of strong winds, tornadoes and very heavy rains in some pockets continues to be elusive.

One of the short-term mitigation measures against TCs is an efficient cyclone warning service. The requirements for such a cyclone warning service (Das 2003) are:

1. advanced accurate and detailed forecasts of dangerous conditions;
2. a rapid and dependable distribution system for the forecasts, advisories and warnings to all interested parties;
   and
3. prompt and effective utilization of warnings by the government and the public.

An essential element of a warning service is that there should be certainty that the warning will reach the intended recipients promptly. The communication system for the distribution of advisories and warnings should be one that can dependably deliver the advisory information to all concerned in the shortest possible time, even in cyclonic conditions of strong wind, heavy rain, flood, etc. The supporting communication systems, including back-up facilities, should therefore be planned and implemented in full detail. The meteorological warning, besides giving precise information about the TC itself and the winds and rainfall to be expected, might also serve as a preliminary warning of a flood and storm surge. Such preliminary warnings should be confirmed or amended in due course by the forecast centre, in conjunction with hydrographers in the case of a storm surge warning.

Damage and destruction due to extreme cold weather in winter results in great economic losses, reduces grain harvest and causes great expenditure on re-sowing of destroyed winter crops. In the majority of cases strong frosts occur as a result of intensive advection of a cold air mass, often accompanied by abundant snowfalls and followed by radiative cooling of air. The likely impact of frost injury can be interpreted from forecasts of extremely low temperatures and the critical temperatures of frost injury for the various crops. This can be determined from average minimum soil temperature at a depth of 3 cm. Snow cover significantly reduces the detrimental impact of low temperatures on winter crops. To make the correct predictions regarding conditions for winter crops, it is necessary to know the duration of standing snow cover. The number of days with snow cover varies regionally and is determined by the intensity of cyclone processes over the regions concerned (Adamenko 2003).

Forest fires are among the main environmental hazards to face at present in many places. They cause injuries and economical losses, with significant impact on ecosystem degradation, soil erosion and flood occurrence. In some countries the problem only occurs during the dry season and mainly affects pine forests, bushlands and sometimes cultivated lands. The use of periodic seasonal data of certain specific forest areas prone to forest fires could be used by the forest managers to enable them taking certain fire prevention measures in advance to mitigate possible damage. On the basis of the weather/fire relationship, a system of fire danger rating has been evolved to guide the fire management people in their day to day activity and also to provide a basis for comparing weather and fire behavior throughout the region. Fire danger ratings do not predict how a specific fire will behave but monitor the potential of fire occurrence (Das 2005a). Such systems usually include book-keeping schemes for keeping track of the moisture contents from one to three size classes of forest fuels, plus indices of spread rate, fuel quantity consumed and energy output rate of the fire front. A forest fire danger rating system in Canada and a universal system of fire danger rating along with fire weather forecasting in the USA are among those providing valuable information to mitigate possible damage due to forest fire (e.g. De Melo-Abreu et al. 2010).

References

Adamenko TI (2003) Hail, high winds and cold injury. In: Das HP, Adamenko TI, Anaman, KA, Gommes RG, Johnson G (2003) Agrometeorology related to extreme events. Technical Note 201, WMO 943, Geneva, 137pp

Curran PJ (1985) Principles of remote sensing. Addison Wesley Longman, NewYork, 282pp

Das HP (2000) Monitoring the incidence of large scale droughts in India. In: Wilhite DA (ed) Drought: a global assessment, Vol.1. Routledge, London/NewYork, pp 181–195

Das HP (2003) Incidence, prediction, monitoring and mitigation measures of tropical cyclones and storm surges. In: Das HP, Adamenko TI, Anaman KA, Gommes RG, Johnson G (2003) Agrometeorology related to extreme events. Technical Note 201, WMO 943, Geneva, pp 35–51

Das HP (2005a) Agrometeorological impact assessment of natural disasters and extreme events and agricultural strategies adopted in areas with high risks. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 93–118

Das HP (2005b) Agricultural drought mitigation and management of sustained agricultural development in India. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 277–303

De Melo-Abreu JP, Daldoum MA, Andrews PL, Bastos TX, De Groot WJ, Fleming R(ichard), Fleming R(obert), Fujioka F, Goldammer JG, Govind A, Harrison J, Keenan T, Price D, Statheropoulos M, Stigter K, Wain A (2010) Applications of meteorology to forestry and non-forest trees. Chapter 11 in “Guide to Agricultural Meteorological Practices”, Third Edition, WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Nunez L (2005) Tools for forecasting or warning as well as hazard assessment to reduce impact of natural disasters on agriculture, forestry and fisheries. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 71–92

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties in Asian regions. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 53–69

Ropelewski CF (1995) Quantification of ENSO precipitation relationships. J Clim 7:1041–1059

Stigter K (2007) Agrometeorological services to prepare farmers for climate extremes and climate use. Paper Presented Under “Agrometeorology and Sustainable Development” at the XVth Congress of the Brazilian Society for Agrometeorology, Aracaju, July. Rev Brasil Agrometeorol 15:202–207

Stigter CJ (2008) Agrometeorology from science to extension: assessment of needs and provision of services. Invited lecture at the 50th anniversary of the Chinese Academy of Agricultural Sciences, Beijing. Agric Ecosyst Environ 126:153–157

Stigter CJ (2009) Scientific support to the establishment and validation of agrometeorological services. SciTopics. Research summaries by experts. Elsevier. http://www.scitopics.com/Scientific_support_to_the_establishment_and_validation_of_agrometeorological_services.html

Stigter CJ, Das HP, Murthy VRK (2003) Beyond climate forecasting of flood disasters. Invited lecture on the opening day of the fifth regional training course on Flood Risk Management (FRM-5) of the Asian Disaster Preparedness Center (Bangkok) and the China Research Center on Flood and Drought Disaster Reduction (Beijing), Beijing, September. Available from ADPC (Bangkok) on CD-ROM. Also available at http://www.agrometeorology.org/fileadmin/insam/repository/ADPC2mp.pdf

Williams J (2000) Drought risk management in Southern Africa. Developing institutions to transform “belated disaster response” into informed preparedness. In: Wilhite DA (ed) Drought: A global assessment, Vol. II. Routledge, London/NewYork, pp 168–177

III.2.4 Tactical Decision Making Based on Weather Information

III.2.4.(I) Problems and Solutions in Using of and Coping with Weather Phenomena in Need of Tactical Decision Making and Challenges Remaining for the Use of Science to Contribute to Problem Analyses and Designing Viable Solutions in this Context: Monocropping

H.P. Das and C.J. Stigter

Weather factors and their analyses in relation to crops and other allied aspects leading to optimization of production have assumed a key role in the agricultural sector. Weather variability is a core factor affecting agricultural production and the information on this aspect needs to be considered in the agricultural planning (strategies) and in tactical decision making processes. Governments typically react to climatic extreme events through "crisis management" rather than preparing in advance the formulation and implementation of anticipatory measures referred to as "risk management" (for high input commercial farming) or "coping with risk" (for most other farming). Since technological inputs quickly reach an optimum level, more emphasis should be placed on designing and selecting weather related tactical applications for effective agricultural coping policies, especially in dryland farming and in other areas with many extreme events. Practices involving such applications need to be worked out with consideration to the weather conditions for monocropping within an individual agro-climatic zone.

The more flexibility farming systems have, the better they can cope with the vagaries of the weather. The more experience locally has been built up and the more exchange of experiences takes place not only from fathers to sons but also from farmer to farmer in farmer organizations, the higher the resilience of these farming systems can be. However, there are great needs for institutionalization of field interactions in an educational setting between farmers and extension scientists with intermediaries, to improve support of tactical decision making. Murthy (2008)

H.P. Das (✉)
Retired from Indian Meteorological Department, Pune, India
e-mail: hpd_ag@rediffmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_20,

in India and Stigter (2008) in Indonesia report on such too rare exercises in agrometeorology.

Deciding to build and maintain facilities for irrigation of agricultural fields and agreements on how to do that (sprinklers, furrows, trickle irrigation) are strategical decisions based on climatic studies of the area and sufficient knowledge of the economics, of plant environments and of agricultural engineering aspects related to land use, the crops and the equipment concerned. Irrigation canals and embankment of rivers that are sources of water in risk zones must be strategically scrutinized to avoid or quickly repair damages. Deciding when to irrigate and with how much water to each of the fields/crops are tactical decisions to be made during each season. The weather phenomena involved are rainfall patterns, particularly rainfall patchiness, agricultural drought and related dry spells that make that the fields need (supplementary) irrigation.

The planning to provide farmers with a decision support system, to assist in such tactical decisions, is again part of the strategical decisions related to agricultural production. The decisions on how to get the advices to farmers and in what form are also parts of this strategy. In the decision support systems developed as a basis for choices when to irrigate where, with how much water, the tactical decisions are prepared. In Part II of this book several operational agrometeorological services have been described that contained details on the strategies and on this latter type of tactical decision making. See Chaps. II.2, II.11, II.16 and II.20 and Sects. II.C.V, II.C.VII and II.C.IX. The provision of the agrometeorological service is itself part of the strategical decisions, the service itself contains the tactics. Some of the best operational agrometeorology is these days available for calculations of the related crop water requirements (Allen et al. 1998; Smith 2000). Their improvements over the last 5 decades of the twentieth century form one of the more important contributions of agrometeorological science to problem analysis and the finding of viable solutions in agricultural production.

Where no water is available or irrigation economically prohibitive, strategical approaches such as distributing fields over large areas with annually varying strong rainfall gradients (rainfed sorghum, Central Sudan, Achmed el-Tayeb Abdalla, Personal Communication 2001) or preventing soil evaporation by something like stone or grass mulches (water melon, Ningxia, China, Liu Jing, Personal Communication 2005/2006/2008; water melon, Jamaica, Donovan Campbell, Personal Communication 2006) need to be applied. The tactics are here in the decisions on the application of fertilizers, on harvesting times and techniques and on field protection of crops and some aspects of transport and storage facilities, of which some are weather sensitive. It is interesting to note that often basically only local literature exists on these cases, if any. Agrometeorology as a science could contribute much more to improving efficiencies of strategies as well as tactics of such cases, if research on such subjects would be selected for local funding and for financial support internationally in aid programmes with the right approach (Stigter 2005). See also Chap. IV.9. Examples may also be found in Stigter et al. (2005a). So much internationally promised aid that does not materialize could be used here!

In dryland farming the corrective measures that can be taken in the event of temporary crop moisture stress depend on the period during which the dry spells occur. If the rain falls immediately after sowing, resulting in a heavy mortality of seedlings, resowing has to be done. If the rain ceases when the crop is 40–50 days old with maximum leaf area, it results in fast depletion of soil moisture in the crop field (Das 2005a). Therefore, tactical reduction of leaf area, either by water rationing or thinning, can mitigate the effects of moisture stress to some extent (e.g. Murthy 2008). Weed control and mulching are other tactical measures that can mitigate drought conditions by conserving the scarce moisture. The advantages of a joint participatory approach under such conditions are discussed in Box III.2.18.

Box III.2.18

Crops that need a short duration to mature and require relatively little moisture need to be encouraged in areas where prolonged dry spells are frequent. Irrigation, through canals and ground water resources, need to be monitored with optimum utilization, avoiding soil salinity and excessive evaporation loss. In low rainfall areas, one of the best tactics for alleviating drought is varietal manipulation, through which drought can be avoided or its effect can be minimized by adopting varieties that are drought resistant at different growth stages (Das 2005b). These are decisions best taken jointly. Selvaraju et al. (2004) evaluated the impact of a participative farm decision-making approach using tactical climate information at different stages of the study period over four seasons from 2000 to 2002.

The results of the study indicated that the percentage of the farmers taking tactical decisions based on weather and climate information was improved during the period under study. The village with the lowest level of resources showed greater overall response to predictions in all four seasons. In the village dominated by commercial crops (Natchipalayam), a maximum of 38% of the farmers followed the predictions and used it for the tactical decision of tomato sowing time. The overall response was lowest in Virugalpatty village due to canal irrigation systems. Farmers in this village used to grow many crops based on water availability in the canal. In general the percentage of farmers taking tactical decisions based on weather and climate was higher during the North East Monsoon rather than the South West Monsoon season. This is because the northeast monsoon season is the dominant rainy season in the area under study, providing 47% of total annual rainfall. The entire irrigated crop production system depends on this season for ground water recharge and the dryland system depends on soil moisture storage.

The climate predictability for the northeast monsoon is relatively better with 2 months lead time (July) using SOI values (Selvaraju et al. 1998). However, the predictability with SOI values may not be sufficient to alter the coping decisions with greater confidence. The climate tactical responsive crop care decisions included nitrogen for top dressing to sorghum, adjusting planting density in cotton and sowing time of chickpea. The joint decisions in on-farm trials are valuable to communicate the concepts to other farmers. The yield and gross margin gain due to use of tactical climate information varied among crops and decisions.

Strategical measures for improving the soil moisture storage through appropriate land configurations also contribute to minimize the moisture deficiency condition for the plants. However, these measures are to be planned well in advance, at least in areas vulnerable to recurring droughts, as stated earlier. In short, the main strategy of mid-season correction revolves around extending the moisture availability period in the soil. Such contingency plans can be well prepared only if rainfall distribution models are developed for different situations and are made available. Here science and extension have still a lot of convincing work to do for the confidential tactical use of such information.

A key factor in protection of crops from cold injury is stable air temperatures, for example with snow covers throughout the winter. The protection of crop damage by frost can be controlled by breaking up the inversion that accompanies intense night time radiation. This may tactically be achieved by heating the air by the use of oil burners that are strategically located throughout the agricultural farm. It can also be done by sucking in cold air from lower parts in an orchard and releasing it somewhat higher in the tree space, after some heating (Hojjat Yazdanpanah, Iran, Personal Communication 2008). Other methods of frost protection include sprinkling the crops with water, brushing (putting a protective cover of craft paper over plants) and burying sensitive plant parts (Paulo Caramori, Brazil, Personal Communication 2005). Preparing for such tactical measures is again part of strategic planning. Avoiding frost by selecting frost free growing situations (e.g. Lomas and Gat 1994), using detailed frost mapping (Lomas et al. 1989), is another strategic approach. Planting winter wheat in furrows for better protection is another one revealed by Stigter et al. (2005b), where many other tactical and strategical traditional examples are given to cope with climate variability. Many of those could use further scientific scrutinizing (see also Parts I and II of this book).

References

Allen R, Pereira LA, Raes D, Smith M (1998) Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. FAO, Rome, 300pp

Das HP (2005a) Agricultural drought mitigation and management of sustained agricultural development in India. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 277–303

Das HP (2005b) Agrometeorological impact assessment of natural disasters and extreme events and agricultural strategies adopted in areas with high weather risks. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 93–118

Lomas J, Gat Z (1994) The economic benefits of frost avoidance for the avocado in Israel. In: Proceedings of the Conference on Economic Benefits of Meteorological and Hydrological Services, WMO/TD 630, Geneva, pp 117–120

Lomas J, Gat Z, Bosruk Z, Raz Z (1989) Frost atlas of Israel, 9 maps, scale 1:100.000, 1 map, scale 1:250.000. Israel Meteorological Service, Bet Dagan, 1 page of explanations

Murthy VRK (2008) Report on the project entitled "WMO-ANGRAU-DST sponsored Roving Seminars on Weather, Climate and Farmers", available on the INSAM website (www.agrometeorology.org) under "Needs for agrometeorological solutions to farmer problems"

Selvaraju R, Balsubramanian TN, Geethalakshmi V (1998) On the variation of north east monsoon rainfall over Coimbatore during warm and cold phases of the El-Nino/Southern Oscillation (ENSO). Vayu Mandal, January–June, pp 50–53

Selvaraju R, George DA, Parunabhaskaran S, Balsubramanian TN, Huda AKS, Geethalakshmi V, Clewett J (2004) Decision making in agriculture using climate information – Indian experience. In: Proceedings of the International Conference on "Seasonal Climate Forecasts in Agricultural Management", Coimbatore, September 2002, pp 77–95

Smith M (2000) The application of climatic data for planning and management of sustainable rainfed and irrigated crop production. Agric For Meteorol 103:99–108

Stigter K (CJ) (2005) Building stones of agrometeorological services: adaptation strategies based on farmer innovations, functionally selected contemporary science and understanding of prevailing policy environments. Paper Presented as the Opening Keynote Lecture at the International Symposium on Food Production and Environmental Conservation in the Face of Global Environmental Deterioration (FPEC, 2004), Fukuoka. Also: J Agric Meteorol (Japan) 60:525–528

Stigter K (2008) Climate change is confusing Indonesian farmers: a visit to another climate field school in Indonesia, that of Gunung Kidul near Yogyakarta. Available at the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology". Also available on http://farmerfieldschool.net/mailman/listinfo/global-ffsl_farmerfieldschool.net

Stigter K (CJ), Kinama J, Zhang Yingcui, Oluwasemire T (KO), Zheng Dawei, Al-Amin NKN, Abdalla AT (2005a) Agrometeorological services and information for decision-making: some examples from Africa and China. J Agric Meteorol (Japan) 60:327–330

Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005b) Using traditional methods and indigenous technologies for coping with climate variability. Clim Change 70:255–271

III.2.4.(II) Designing and Selecting Weather Related Tactical Applications for Agricultural Management and Increasing Their Efficiencies: Monocropping

H.P. Das and C.J. Stigter

Sustainable agricultural production needs activities which provide information aimed at helping tactical decision makers apply weather and climate information to minimize negative consequences of adverse weather and to take advantage of favorable weather conditions. In order to benefit from weather and climate information, decision makers must possess flexibility to change their practices in response to the improved information (Sonka et al. 1986). Most difficulties in decision making become apparent with the identification and recognition of available alternatives, the determination of relevant attributes, and collection of relevant information (Backus et al. 1997). Farmer participation is encouraged for the development and promotion of new agricultural strategies and tactics suited to low-resource farmers living in environments described as complex, diverse and risk prone (Bruntland 1993). Participatory methods are required to meet farmer needs in less productive and highly variable environments, helping to make better informed tactical farm decisions (Hartmann et al. 2002).

Meteorological conditions influence important farming operations such as planting and harvesting, and greatly influence yield at critical stages of crop development. The decision-makers in extension are interested in monitoring and short-term foretelling of the agricultural season to help the farmers in adverse years and to provide agroclimatological information for agricultural planning (Das 2005a). The farmers require this information to allow them to take tactical decisions in terms of crop care, whether to sow or not, to sow what and in what density, to spray or not, what to spray and how often, to irrigate or not and if the decision is made to irrigate, what should be the amount of irrigation etc. It is clearly necessary to ensure that any farm level tactics based on weather are practical, affordable and acceptable to farmers. Particular attention should be given to analyzing the economic, social, institutional and cultural factors related to the tactical decisions made for agricultural actions. Stigter et al. (2007) discussed farmers' conditions and requirements using new weather and climate information approaches and technologies.

H.P. Das (✉)
Retired from Indian Meteorological Department, Pune, India
e-mail: hpd_ag@rediffmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_21,

The endeavor to seek appropriate crops/varieties and coping practices for the complex heterogeneous rain-fed ecosystems, on which the impact of temporal variations of environment and particularly rainfall is large, will succeed only if such a farmer-centered approach is adopted. The tactical decisions will be specific to applications in the farming situation, the agro-climatic regime and the expected climate variability concerned.

Instead of a package of recommendations derived by scientists, on the basis of experiments in the field station and theoretical studies, a decision support system needs to be introduced. This can help the farmer choose rationally between various available options on the basis of the state of the crops, soils, pests, diseases etc. and the predictions throughout the season. In Part I the Mali agrometeorological pilot projects were an example of such a system (see also WMO 2010). This section discusses some aspects of tactical applications for crop production that are sensitive to present and future weather conditions and the conditions that have to be fulfilled to succeed. Examples for flood conditions are discussed in Box III.2.19.

Box III.2.19

Floods and heavy rainfall cause great damage to agricultural production systems. In rain-fed agricultural systems, farmers typically anticipate rainfall during the growing period sufficient to naturally or artificially irrigate crops. In both situations, however, there is often a balance needed between retaining enough water for agricultural production and environmental health and maintaining enough available storage volume to capture incoming water and prevent floods. Here, analysis of past weather and water data are critical for estimating average conditions and inherent variability in response farming. Crops like rice, that can function effectively in saturated and even submerged conditions, are appropriate for locations that flood regularly, and systems become dependent upon regular flooding. Flood plain maps with appropriate information about probabilities (return period) of certain amounts of precipitation and/or depth of flooding water should be developed and used in risk assessments for tactics and agricultural strategical planning (Das 2005b).

Geographical Information Systems (GIS) can be used to develop new flood plain maps at various frequencies and severity levels. This system delineates wetlands in many regions and countries, using geospatial analyses of multiple spatial layers as well as others, including aerial photographs. Such information will certainly assist in the best strategical design of agricultural systems, while tactically accounting for reasonable risk.

Another aspect that might be considered in strategical or tactical preparedness is related to the influence of flood water on the nutrient conditions of the soil (Ludwick 1997). Nitrogen in the form of nitrate is either leached away or denitrified. Prolonged wetting slows down decomposition of organic matter in and on the soil (mulch) as a source of N for crop use. Phosphorous is lost by water erosion of top soil, reduced microbial activity in saturated soil reduces P availability and depressed mycorrhizae due to flooding decrease P absorption by roots. More flooding related effects affect P. Potassium (and other nutrients) availability is reduced by compaction, so working too wet soils may be disastrous. Such K availability is for example particularly important for perennials weakened by prolonged flooding and especially prone to development of disease problems, which are reduced by potassium (Ludwick 1997).

Although these facts come from a paper on fertilizing after floods, the above and related knowledge could possibly deliver a strategy for nutrient tactics of various types of soils and farming systems before the start of recurrent flood seasons, that would reduce negative aspects on soil fertility. Knowledge is power. Each field of science can make a contribution to better preparedness (Stigter et al. 2003).

The tropical cyclone causes irreparable damage to the agriculture, ranches and forest (Das 2003). Preparedness for cyclones in the agricultural system can include early harvesting of crops, if matured, safe storage of the harvest (e.g. Murthy 2008) etc. In the cyclone hit areas, the traditional varieties, which are heavily shredded by nature and are susceptible to easy lodging in high impact of wind, should be avoided. The farmers in these regions should be advised to take up the cultivation of those short-duration variety crops which are not easy grain shredders.

Under rainfed conditions, the farmers in India have learned to keep their cropping practices flexible so that corrective measures can be introduced, depending on the type of weather aberrations (Subbiah 2000). Normally, the following kinds of aberrations are observed under rain-fed conditions:

- delayed onset of monsoon rains;
- long break in rainfall during the middle of the rainy season;
- lack of rainfall during the post-rainy season; and
- high soil temperature at sowing time (in case of post-rainy season crops).

In response to late onset of rainfall conditions, farmers change from long duration high-yielding crop varieties to short-duration low-yielding varieties. The mid-season correction for each aberration varies from place to place, depending on the rainfall pattern, soil type, choice of crop, and so forth. Corrective measures include reducing the plant population by thinning crops to reduce crop competition for available moisture and providing supplemental irrigation in case there is a long break in rainfall during the crop season (Das 2000; Murthy 2008). However, there are very few options to manage terminal droughts due to early withdrawal of the monsoon. Harvesting the crop for fodder is the only way to slightly reduce the damage.

Nevertheless, most of the drought coping strategies need to be adopted from the beginning of the season in order to be effective. In other words, "one has to plan for coping with drought, before planting the crops, even if the forecast is for a good year". Therefore, the farmers tactically sow a mixture of crops instead of using monocropping and they thin out the crop stands as the intensity and duration of rainfall becomes clearer with the passage of time.

Nicholls (1999) discussed some of the constraints to the effective use of tactical climate information. He suggested that forecasters and decision makers need to understand the difficulties faced by the users and to make adjustments for them in the ways information is prepared and disseminated. A significant problem remains in translating the seasonal climate forecast information into appropriate tactical action by farmers to minimize or evade risk. The issues include how climate and weather information can be used to make improved tactical decisions for a number of practices including crop/variety selection, sowing time, sowing area, fertilizer application, harvesting, prediction and estimation of yields, determination of crop quality and market values. Farmers bear the consequences of the decisions.

For some farmers it is not just an issue of profit and loss and resource management but a question of whether they can grow enough food to feed their family and livestock. Thus it is very important for the researchers, extension and community workers to build rapport with farmers based on trust and mutual respect. Providing only definitive answers using scientific knowledge and climate models is not what farmers need (Weiss et al. 2000). Through dialogue with farmers, extension officers and researchers from other disciplines, it was realized that farmers had few options in their coping processes to use this complex information. What they needed were relatively simple rules of thumb at critical points such as planting, harvesting etc. to make better informed tactical decisions that minimized their risk and maximized their opportunities as far as was possible.

Potential to improve agricultural production in developing countries can be achieved by "a more accurate climate forecasting system" combined with participative decision making and localized forecasts that meet the end users tactical needs (Hartman et al. 2002). Huda et al. (2004) described the experiences of applying seasonal climate information for agricultural management in Australia with emphasis on collaborative research and implementation by scientist-farmer interactions. These were, however, mostly strategical decisions.

References

Backus GBC, Eidman UR, Dijkhuizen AA (1997) Farm decision making under risk and uncertainty. Neth J Agric Sci 45:307–328

Bruntland GH (1993) Our common future, world commission on environment and development. Oxford University Press, Oxford/NewYork, pp 120–122

Das HP (2000) Monitoring the incidence of large scale droughts in India. In: Wilhite DA (ed) Drought, a global assessment, Vol. 1. Rauteldge, London/NewYork, pp 181–195

Das HP (2003) Incidence, prediction, monitoring and mitigation measures of tropical cyclones and storm surges. In: Das HP, Adamenko TI, Anaman KA, Gommes RG, Johnson G (2003) Agrometeorology related to extreme events. Technical Note 201, WMO 943, Geneva, pp 35–51

Das HP (2005a) Agricultural drought mitigation and management of sustained agricultural development in India. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 277–303

Das HP (2005b) Agrometeorological impact assessment of natural disasters and extreme events and agricultural strategies adopted in areas with high weather risks. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 93–118

Hartmann H, Pagano TC, Sorooshian S, Bales R (2002) Confidence builders: evaluating seasonal climate forecasts from user perspectives. Bull Am Meteorol Soc 83:683–698

Huda AKS, Truelove N, Wallace G, Packham RG, Balsubramanian TN, Selvaraju R, Geethalakshmi V, George DA, Clewett JF (2004) Decision making in agriculture using climate information: Australian experience. Proceedings of the International Conference on "Seasonal Climate Forecasts in Agricultural Management", Coimbatore, September 2002, pp 64–76

Ludwick AE (1997) Fertilizing after floods. In a compilation by Johnson G: the impact of flooding and heavy rainfall on agriculture. In: Das HP, Adamenko TI, Anaman KA, Gommes RG, Johnson G (eds) Agrometeorology related to extreme events. Technical Note 201, WMO 943, Geneva, 137pp

Murthy VRK (2008) Report on the project entitled "WMO-ANGRAU-DST sponsored Roving Seminars on Weather, Climate and Farmers", available on the INSAM website (www.agrometeorology.org) under "Needs for agrometeorological solutions to farming problems"

Nicholls N (1999) Cognitive illusions, heuristics and climate prediction. Bull Am Meteorol Soc 80:1385–1397

Sonka ST, Lamb PJ, Hollinger SE, Mjelde JW (1986) Economic use of weather and climate information: concepts and an agricultural example. J Climatol 6:447–457

Stigter CJ, Das HP, Murthy VRK (2003) Beyond climate forecasting of flood disasters. Invited Lecture on the Opening Day of the Fifth Regional Training Course on Flood Risk Management (FRM-5) of the Asian Disaster Preparedness Center (Bangkok) and the China Research Center on Flood and Drought Disaster Reduction (Beijing), Beijing, September. Available from ADPC (Bangkok) on CD-ROM. Also available at http://www.agrometeorology.org/fileadmin/insam/repository/ADPC2mp.pdf

Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Naguyen van Viet, Bakheit NI, Abdullahi (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, NewYork, pp 171–190

Subbiah AR (2000) Response strategies of local farmers in India. In: Wilhite DA (ed) Drought: a global assessment. Vol.1 Routledge, London/NewYork, pp 29–34

Weiss A, Van Crowder L, Bernardi M (2000) Communicating agrometeorological information to farming communities. Agric For Meteorol 28:165–196

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by Stigter CJ. WMO, Geneva, in print

III.2.5 Developing Risk Management Strategies

III.2.5.(α) Defining, Managing and Coping with Weather and Climate Related Risks in Agriculture: Monocropping

Kees Stigter

Many examples collected by Baier (2000, 2004) deal with defining and coping with weather and climate risks in agriculture and some also with related strategical and policy matters. The prize winning and other (see Part II) examples of the INSAM (2006–2008) contests of best examples of agrometeorological services are most often also related to coping strategies with such risks. Some more agrometeorological case studies may be found in WMO (2001, 2004, 2010).

Sahni and Ariyabandu (2003) stated that there is a strong need to move from an "emergency management culture" to one of disaster preparedness. They urged its fostering in disaster risk reduction through focusing in community planning on prevention, mitigation, response, recovery, rehabilitation and reconstruction. With international support, this preparedness tendency slowly moves the right way (e.g. Hollister 2007).

This applies to monocropping as well as other modes of agricultural production, and also to applied agrometeorology (Stigter et al. 2003). Sikka (2001) was the first to define the role of media in such disaster preparedness and Stigter et al. (2007) explicitly proposed to abandon the term "risk management" for all but the richest farmers. To these may be added those working in centrally managed agriculture (e.g. Brunetti et al. 1997).

Design abilities of risk management strategies – these days possibly on a commercial basis (Stigter 2006), or centrally managed (e.g. Jamieson et al. 2001) – and of coping strategies with risk – for various income groups as for example distinguished by Stigter et al. (2007) in China – need a role of science in such explicit preparedness approaches (Murthy and Stigter 2006). See also Sect. III.2.5.(δ).

Organization wise, agrometeorological services are indeed the road to go. Box III.2.20 derived from WMO (2010) gives the required details.

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_22,

Box III.2.20

The following is organizationally of basic importance in establishing agrometeorological services. The core idea was developed and applied in Africa, Asia and Latin America that agrometeorological services can be established with farmers from farmer experience and/or (information) products that are offered by meteorological services, research institutes and universities. Five basic issues have to be addressed in pilot projects for the establishment of agrometeorological services (see also Sect. I.5.4):

1. Determination of needs and priority problem selection.
2. Target group differentiation and fine tuning of information needs assessment and problem definition.
3. Product selection, improvement and focusing (client friendliness).
4. Development and establishment of agrometeorological services (risk communications leading to preparedness and mitigations) from those products by applied scientists, government and NGO extension intermediaries and farmers.
5. Upscaling from pilot projects through training exercises.

For the first two basic issues, experience in Africa and Asia indicates that questionnaires (through interviews) with farmers are essential. Otherwise it remains unclear whether the choices were made by farmers or extension or scientists, and in the latter cases whether the choice was at least farmer supported as a priority problem related to their priority needs. For the third basic issue, it should be realized that forecasts, predictions, models, decision analyses, communication methods (including participative research) are tools that only become (information) products when they can be operationally used by others down the line towards farmers for better preparedness and mitigation decisions (see also Sect I.5.4). As to the fourth basic issue distinguished above, the question is where and how to focus to have problems operationally tackled by products (still with the differentiations applied):

- collect existing agrometeorological services of the kind related to explicitly available products identified, if any; determine the communication channels;
- determine which (information) products need to be focused on which priority problems; and which applied scientists (from which institutions), extension intermediaries and farmers should be involved in making these products into services along which communication channels;
- organize the establishment of such agrometeorological services in risk communication (such as in response farming) along the right channels, using extension intermediaries where appropriate.

As to the fifth basic issue distinguished above:

- any agrometeorological service so detected or established with a target group of farmers through certain communication channels (from products operationally used to solve priority problems) in pilot projects, should be considered for upscaling. This may for example be done through the development of training modules for extension intermediaries (working at the institutions concerned or along the communication channels established) to be used in Farmer Field Schools (FFSs);
- in first instance these will be farmers in the same category of differentiation, because for other groups the best approaches could be different.

In conclusion, the lessons learned still point towards a need to, by all means, bridge the gaps towards the livelihoods of farmers. For any lasting success of agrometeorological services, such bridging should be funded, organized and permanently evaluated through the training of intermediaries. Climate change makes this only more necessary (WMO 2010).

References

Baier W (2000) WMO/CAgM-related achievements in agricultural meteorology. CAgM Report 83, WMO/TD 1033, Geneva, 27pp

Baier W (2004) Case studies of economically beneficial agrometeorological applications and services and other success stories in agrometeorology for policy matters. CAgM Report 93, WMO/TD 1202, Geneva, 79pp

Brunetti A, Ford PB, Kanemasu ET, Lablans WN, Mills PF, Mulder R, Sirotenko OD, Wang F (1997) Weather/climate and sustainable agricultural production and protection. CAgM Report 74, WMO/TD-838, Geneva, 112pp

Hollister D (2007) RI government moves to reduce disaster risks. Jakarta Post of 10 September, p 6

INSAM (2006–2008) Best examples of agrometeorological services. www.agrometeorology.org under “Accounts of Operational Agrometeorology”

Jamieson PD, Agbangla AD, Diemer P, Jagtap SS, Lansigan F, Strand JF, Strashny VN, Wang S (2001) Agrometeorological information needs in agricultural production. CAgM Report 85, WMO/TD 1030, Geneva, 89pp

Murthy VRK, Stigter CJ (2006) Operational agrometeorological services for extension needs and the supportive role of agricultural research. In: Strengthening operational agrometeorological services at the national level, Manila. AGM-9, WMO/TD 1277, Geneva, pp 199–208

Sahni P, Ariyabandu MM (2003) Disaster risk reduction in South Asia. Prentice-Hall of India, New Delhi, 372pp

Sikka K (2001) Role of media in disaster preparedness. In Sahni P, Dhameja A, Medury U (eds) Disaster mitigation: experiences and reflections. Prentice Hall of India, New Delhi, pp 124–131

Stigter K (2006) Agrometeorological services in various parts of the world, under conditions of a changing climate. Austin Bourke Memorial Lecture presented in the Royal Irish Academy, Dublin. Extended Abstract on the INSAM website under “Accounts of Operational Agrometeorology”. www.agrometeorology.org

Stigter CJ, Das HP, Murthy VRK (2003) Beyond climate forecasting of flood disasters. Fifth Regional Training Course on Flood Risk Management, ADPC, Beijing. http://www.agrometeorology.org/index.php?id=273

Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi YM (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha R (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 171–190

WMO (2001) Contributions from Members on operational applications in agrometeorology and from discussants of the papers presented at the international workshop "Agrometeorology in the 21st Century, Needs and Perspectives". CAgM Report 77b, WMO/TD 1029, Geneva, 175pp

WMO (2004) Contribution from Members on operational applications in agrometeorology and from discussants of papers presented at the International Workshop "Reducing Vulnerability of Agriculture and Forestry to Climate Variability and Climate Change". CAgM Report 94, WMO/TD 1213, Geneva, 94pp

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by Stigter CJ. WMO, Geneva, in press

III.2.5.(β) Developing Scales and Tools for Weather and Climate Related Risk Quantifications: Monocropping

Kulasekaran Ramesh, Roger E. Rivero Vega, and Kees Stigter

Every assessment of the plausible impacts of climate variability and change on any sector must be based on an as far as possible quantitative appraisal of what future climate will look like and how its variability will be. But it happens that future climate conditions and variability can't be predicted in the same sense that the weather for the next 5 days can be forecasted in national meteorological services. A forecast is made by the procedure of applying statistical relationships derived on a dependent sample between the state of the atmosphere at a given date and its state at a latter date, or solving the time dependent system of coupled partial differential equations of hydrothermodynamics. In both cases external influences that could exert a given action on the meteorological system during the lapse of time existing between the initial and the final date are not taken into account (Rivero Vega 2008).

Beside this, the development of science has been gradually reaching a point in which the deterministic behaviour of atmospheric and weather processes is being questioned in the sense of making doubtful the notion of weather predictability in a mechanistic way, because of the infinity of interactions and feedbacks that confers atmospheric behaviour a rather chaotic nature. This kind of notion in fact implies that a certain amount of unpredictability is embedded in the atmospheric system itself, because of its nature, and can't be attributed only to our limited scientific and technological knowledge. This leaves us only the possibility of drawing an educated guess of what earth climate will look like at a future date. That educated guess is what we'll be calling here a climate change scenario to distinguish it very clearly from a climate change forecast (Rivero Vega 2008).

The usual procedure of creating a climate change scenario begins by making a whole set of reasonable assumptions about the future actions of human society during a certain lapse of time, let's say a century. These assumptions give rise to what we usually call a storyline depicting a set of plausible paths of development for man on Earth. For a given story line there will be a description of the relative use of different kinds of energy sources, population growth, expected income and livelihood of people on

K. Ramesh (✉)
IHBT(CSIR), Palampur, India; IISS(ICAR), Bhopal, India
e-mail: ramechek@yahoo.co.in

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_23,

this planet. From the point of view of climate change science these storylines allow us to estimate what the emissions of greenhouse gasses will be during the lapse of time involved between an actual and a future date. The expected changes in atmospheric concentrations of greenhouse gasses (carbon dioxide, methane, ozone, chlorofluorocarbons and oxides of nitrogen) are then derived from these assumptions using appropriate physicochemical models. The final result of this process is what is usually called a greenhouse gases (GHG) emissions scenario (Rivero Vega 2008).

The output of global and regional climate models can be used directly to generate the necessary climate change scenarios for an assessment of the agricultural sector and this is not an easy task for an assessment team. Complete outputs from global or regional climate models are not usually available and to obtain them requires collaboration among diverse institutions in different countries. It is usually recommended that climate change scenarios using different and contrasting global climate models (an ensemble approach) should be used to incorporate the existent uncertainties derived from the fact that different global climate models give different results for some particular regions, especially in relation to precipitation regimes. Rivero Vega (2008) reviewed some of the presently available scenario approaches for climate impact assessment teams (see also Box III.2.21).

Box III.2.21

Rivero Vega (2008) argues that the use of climate indexes in agricultural or natural ecosystems impact assessments is rarely done for a limited (point) locality, a circumstance very frequent when we are using process-based crop models. Climate indexes are naturally related to areal, regional or national assessments because they are scalar quantities that can be easily converted to isograms in maps depicting spatial variations of the study object and thus allowing appreciation of derived conclusions at a glance. Speaking of spatial variability of some numerical magnitude associated to some specific conceptual interpretation these days always leads people to think in terms of Geographical Information Systems (GISs) and its associated technological and knowledge complexities.

However, we must never forget that GISs are only a modern achievement and that a map of practically every conceivable variable can always be done manually following the standard rules of scalar analysis as they apply to the magnitude of the task at hand. Nobody needs to become a specialist in GIS in order to make a useful map of a climate index and obtain the necessary conclusions from it (Rivero Vega 2008). Conclusions derived from spatial representations of a climate index are most of the time inferred from the index values and not directly calculated from them. This is particularly the case of aridity indexes or Holdridge's Life Zones. Notwithstanding this, that is not the case of some indexes such as the Riabchikov's indexes and other ones because these can be directly transformed to net primary productivity of ecosystems, or to some other directly meaningful biological concept, before making the final assessment map. In fact, net primary productivity of ecosystems calculated by using such indexes or Lieth's formulas could be considered as climate indexes instead, because they rarely take into account other factors such as soil properties or human intervention on landscapes (Rivero Vega 2008). In addition to agroecological zoning, impact assessment on water resources and Cuban case studies of integrated impact assessments, Rivero Vega (2008) deals with aridity indexes, net primary productivity of forests and human and animal comfort indexes, as bioclimatic indexes in impact assessments.

Climatic risk in crop production has simply been defined as a probability of occurrence of unfavorable weather conditions affecting crop performance (Rotter 1993). Weather related risks are a major source of uncertainty in agriculture (e.g. Meinke et al. 2003; Rathore and Stigter 2007; Sivakumar 2008; and various contributions in the previous sections of this Chap. III.2 as far as monocropping is concerned). Quantifying or having quantified this is important to farm managers, researchers and policy makers at macro level. Hence, it is necessary to formulate suitable scales and tools for weather and climate related risk quantification. Currently there are many opportunities that can assist in coping effectively with agrometeorological risks and uncertainties (e.g. Meinke and Stone 2005; Rathore and Stigter 2007). One of the most important strategies is improved use of climate knowledge and climate risk technologies. Both structural and non-structural measures can be used to reduce the impacts of the variability (including extremes) of climate resources on crop production (Wilhite 2005). Planning, early warning and well-prepared response strategies are the major tools for mitigating losses, but as Lassa (2008) has argued, in the end warning systems are about people.

Simple scale criteria were used to identify and evaluate drought and water logging of maize crops adapted in Jilin province, China, by considering agrometeorological features and stage of crop growth (Table III.2.1, Zhang et al. 2004). Cool summer was as a simple scale condition of low temperature (higher than 0 °C) sufficient to have an adverse effect on crops during the growing season (Zhang et al. 2005). Tomar (2000) developed crop-weather-disease-interaction for potato late blight disease and rated the disease intensity in a 0–9 scale (Table III.2.2). Above normal rainfall in November enhanced *Helicoverpa armigera* activity in Pigeonpea monocropping in Karnataka, India. This method of a single indicator has

Table III.2.1 Criteria of drought and water logging according the Rainfall Anomaly Ratio (%) (RAR). (Zhang et al. 2004). RAR= $(R - R_m)/R_m$ where R is the rainfall during a defined period, and R_m is the mean rainfall during that period

Drought	Water logging
Spring $RAR_{April–May} < -30\%$ Summer $RAR_{June–August} < -30\%$ Autumn $RAR_{September–October} < -50\%$	RAR_{June} or RAR_{July} or $RAR_{August} \geq 100\%$

Table III.2.2 Disease rating for potato late blight (Tomar 2000)

Scale	Percent diseased area	Scale	Percent diseased area
0	Nil	6	41–55
1	1–5	7	56–70
2	6–10	8	71–85
3	11–20	9	>85
4	21–30		
5	31–40		

Table III.2.3 Correlation coefficients between rainfall and sorghum shoot fly (Venkatesh 2008)

Lead time (weeks)	Sowing month		
	September and October	September	October
4	−0.36	−0.22	−0.56
3	−0.02	0.20	−0.41
2	−0.08	0.12	−0.40
1	0.22	0.18	−0.10

been found effective by the University of Agricultural Sciences, Dharwad, for undertaking field operations at a large scale (Venkatesh 2008). Another example of this kind is that sorghum shoot fly incidence is particularly negatively correlated with rainfall occurring four weeks earlier (Table III.2.3, Venkatesh 2008). Goraya and Hundal (2006) observed an increase in disease intensity with cumulative wetness duration measured through a portable leaf wetness recorder at mid canopy height. Although this is a single parameter measure too, it is a much more complicated one to work by and not suitable as a routine indicator.

More complicated tools were used where incidence of grape mealy bug correlated significantly negatively with minimum temperature, bright sun shine hours and rainfall during real time and at three lead weeks, but positively with morning and afternoon relative humidities at two and three lead weeks respectively during the pre-monsoon season (Venkatesh 2008). Harrison and Lowe (1989) reported that the temperature for potato late blight infection varies from 5 to 25 °C with an optimum around 15 °C and maximum growth of hyphae at 20 °C. Reddy et al. (2006) developed a Dynamic Cumulative Weather Based Index (DCWBI) for forewarning of rice blast. The value lies between 0 and 1. All these quantitative scales and tools could basically be used for the development of risk reducing agrometeorological services as discussed in many parts of this book (see also Stigter 2008).

Zullo et al. (2006) used Water Requirement Satisfaction Index (WRSI) values during the reproductive stages (flowering and grain-filling stages) to assess the suitability of a planting dekade: suitable or favorable (when the WRSI value was greater than or equal to a chosen threshold value) and unsuitable (when the WRSI value was lower than a chosen threshold value) to analyse the climatic risk for coffee and corn in Brazil. Much more complicated simulation studies as tools of assisting dryland maize production in areas of highly variable rainfall indicated for example for north-east Australia that maize is a viable dryland cropping option provided that cultivar, sowing time and starting water conditions are optimized (Birch et al.

2008). Meinke et al. (1992) developed a model to quantify climatic risk to dryland sunflower production.

Crop simulation analysis of soybean showed that climatic risks to soybean production at Kota, Rajasthan, India is much more than that at Indore (India) and Rajgarh (India). At Kota, the simulated grain yield varied from 120 to 3,820 kg ha^{-1} with rainfall variability, with a mean of 1,340 kg ha^{-1} and a coefficient of variation of 76% (Singh and Srinivas 2007). A dynamic peanut simulation model was developed by Meinke and Hammer (1995) to quantify climatic risk to peanut production in northern Australia. They demonstrated how district yield information could be usefully combined with simulation results to objectively assess impacts and causes of climatic variability on production. The pod zone soil temperature for groundnut, simulated by the Agricultural Production Systems Simulator Model (APSIM), is now generally relied on in stead of measured input of soil temperature in applications, to quantify climatic risk of aflatoxin accumulation (Chauhan et al. 2008). A model was also developed to quantify climatic risks of aflatoxin contamination in maize using principles previously used for groundnut. The model outputs an aflatoxin risk index in response to seasonal temperature and soil moisture during the maize grain filling period using the APSIM's maize module (Chauhan et al. 2007).

References

Birch CJ, Stephen K, McLean G, Doherty A, Hammer GL, Robertson MJ (2008) Reliability of production of quick to medium maturity maize in areas of variable rainfall in north-east Australia. Aust J Exp Agric 48:326–334

Chauhan Y, Wright G, Rachaputi NR, Krosch S, Robertson M, Hargreaves J, Broome A (2007) Using APSIM-soil temp to simulate soil temperature in the podding zone of peanut. Aust J Exp Agric 47:992–999

Chauhan Y, Wright G, Rachaputi NR (2008) Modelling climatic risks of aflatoxin contamination in maize. Aust J Exp Agric 48:358–366

Goraya KS, Hundal SS (2006) Potato late blight and weather relationships under different sowing dates and weather conditions. J Agromet 8:210–214

Harrison JG, Lowe R (1989) Effect of humidity and air speed on sporulation of *Phytophthora infestens* on potato leaves. Plant Pathol 38:585–591

Lassa J (2008) Warning system is about people. Jakarta Post of 27 November, p 6

Meinke H, Hammer GL (1995) Climatic risk to peanut production: a simulation study for Northern Australia. Aust J Exp Agric 35:777–780

Meinke H, Stone, RC (2005) Seasonal and interannual climate forecasting: the new tool for increasing preparedness to climate variability and change in planning operations. Clim Change 70:221–253

Meinke H, Hammer GL, Chapman SC (1992) Using a model to quantify climatic risk to dryland sunflower production. Proceedings of the Australian Agronomy Conference, Australian Society of Agronomy, Perth. http://www.regional.org.au/au/asa/1992/refereed/2/03 modelling -09.htm

Meinke H, Wright W, Hayman P, Stephens A (2003) Managing cropping systems in variable climates. In: Pratley J (ed) Principles of field crop production, 4th edn. Oxford University Press, Melbourne, pp 26–77

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties-Regional Perspectives: Asia. In: Sivakumar MVK and Motha R (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 53–69

Reddy DY, Prabhakar M, Ramakrishna YS, Reddy CS, Prasad YG, Nagalakshmi T (2006) Dynamic cumulative weather based index for forewarning of rice blast. J Agromet 8:1–6

Rivero Vega RE (2008) Workbook of climate change impacts assessments in agriculture. Basic knowledge, methodologies and tools. Cuban Institute of Meteorology/Caribbean Community Climate Change Centre. Available on the INSAM website (www.agrometeorology.org) directly from the homepage.

Rotter R (1993) Simulation of the biophysical limitations to maize production under rainfed conditions in Kenya. Evaluation and application of the model WOFOST. PhD Thesis, University of Trier. Materialien zur Ostafrika-Forschung, Heft 12. Geographischen Gesellschaft, Germany, 297pp

Singh P, Srinivas K (2006) Crop simulation models as decision-making tools for managing agricultural drought. In SERC School on agricultural drought: aspects of micrometeorology. CRIDA, Hyderabad, pp 96–100

Sivakumar MVK (2008) Climate risk management in agriculture. Souvenir, International Symposium on Agrometeorology and Food Security, CRIDA, Hyderabad, pp 10–17

Stigter CJ (2008) Operational agrometeorology: problems and perspectives. In: Souvenir, International Symposium on Agrometeorology and Food Security, CRIDA, Hyderabad, pp 41–47

Tomar K (2000) Crop-weather-disease interaction studies on late blight of potato. M.Sc. Thesis, Punjab Agricultural University, Ludhiana, no pages

Venkatesh H (2008) Weather and pests. AICRP on Agrometeorology – Bijapur. CRIDA, Hyderabad, pp 1–31

Wilhite DA (2005) The role of disaster preparedness in national planning with specific reference to droughts. In Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin, pp 23–38

Zhang Jiquan, Okada N, Tatano H, Hayakawa SJ (2004) Damage evaluation and regionalization of agro-meteorological disasters in the maize-growing region of Songliao Plain, China: Case study of Lishu area of Jilin Province. Natur Haz 31:209–232

Zhang Jiquan, Hayakawa S, Zhou Daowei, Zhang Hui (2005) Risk assessment and regionalization of agro-meteorological hazards in Jilin Province, China. J Agric Meteorol 60:921–924

Zullo Jr J, Pinto HS, Assad DA (2006) Impact assessment study of climate change on agricultural zoning. Meteorol Appl 13:69–80

III.2.5.(γ) Improving Weather and Climate Related Risk Assessments in Agricultural Production: Monocropping

Kulasekaran Ramesh and Kees Stigter

The agricultural sector is characterized by high exposure to risk, often but not only coming from climatic events (e.g. Rathore and Stigter 2007). The term "risk assessment" has for example been used to define the prediction of likely damaging levels of existing and newly developed pests and diseases on various scales, from on-farm disease prediction to regional impact assessments of new pests (e.g. Strand 2000). In other words, a risk assessment is aimed at generating information on the likelihood of the occurrence of a disease on specific scales determined by users. The most important part of a climatic risk assessment is to decide whether the expected erratic behavior of the weather/climate will be significant for crop production (e.g. Brunini et al. 2008). This assessment forms a basis to determine what measures can be taken to minimize the risk to an insignificant level (e.g. Singh et al. 2000).

In India, there is a growing list of weather based pest and disease models. Conditions for weather warnings are given together with weekly normal weather conditions for relevant months and the mean dates of important epochs of crop growth and pest development. This way, moments for action can be determined (WMO 2010). Drought represents one of the major threats caused by weather and climate to farming, leading to poverty. The characterization of agricultural drought risk and the assessment of its possible impact are of greater importance for policy makers (e.g. Stigter 2004; WMO 2006). Also many examples below therefore relate to drought risk assessments.

Kates and Kasprson (1983) discussed three distinct steps for risk assessment:

(a) An identification of hazards likely to result in disasters, e.g. what hazards events may recur?
(b) An estimation of the risks of such events, e.g. what is the possibility of such events?
(c) An evaluation of the social consequences of the derived risk, e.g. what is the loss created by each event? (see also Box III.2.22).

K. Ramesh (✉)
IHBT(CSIR), Palampur, India; IISS(ICAR), Bhopal, India
e-mail: ramechek@yahoo.co.in

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_24,

Box III.2.22 (Contributed by Roger E. Rivero Vega)

Once we have a suitable baseline, then a projected future climate is obtained using specific techniques (Rivero Vega 2008). This projected future climate should be envisioned in the frame of an accompanying socioeconomic scenario. The combination is called a climate change scenario. Once we have both a reference baseline and a projected climate change scenario, very sophisticated impact tools and methodologies are applied to current and projected climate and socioeconomic scenarios, explaining the risks involved. Results obtained with the same impact tools in the two different situations (actual and projected) are compared to obtain an assessment of the expected climate change impact on basic parameters characterizing the sector as a whole or a part of it (Rivero Vega 2008). Once the impact of climate change has been assessed, an analysis of possible adaptation measures and strategies, that is how to cope with the risks, is done and its expected results are estimated using the same impact tools that were used to derive the original impacts. This complex intercomparison of results constitutes the basis for the elaboration of recommendations about strategies, policies and adaptation measures that could be adopted to minimize, eliminate or even revert the negative impacts of climate change in the agricultural sector. It must be stressed that an adaptation option should never be created from thin air. Every adaptation option should be derived by making a thorough study of its possible outcomes, using the same impact tools used to derive the expected impacts of climate change. After completion of such an intensive research effort by an assessment team, a comprehensive set of adaptation measures and strategies becomes available for policy and decision makers. The actual implementation of those recommendations now becomes a very important issue in societal efforts of minimizing the possible negative impacts of climate change in basic issues such as food security, income and the livelihoods of people (Rivero Vega 2008).

Farmers are more concerned about the choice of crops that are appropriate for the changing weather and climatic conditions and more conscious about site-specific crop management so that the input costs are minimal and less risky (Maracchi et al. 2006). Farming in many parts of the world, especially in the arid and semi-arid regions of the developing countries, is risky, because climate is highly variable (Sivakumar 2006) and forecasting knows many constraints (Stigter 2004). Irrespective of their resource endowments, farmers share some common possibilities to cope with variability and changes in environmental conditions and associated risks (Rotter and van Keulen 1997): (a) choice of crop species, crop cultivars and rotations; (b) choice of location within the farm for specific crops; (c) choice of planting dates and intensity of cultivation; (d) frequency and timing of fieldwork.

In disease risk assessment, the most needed information in terms of occurrence of a disease is:

- areas identified in a region or countries that are favorable or unfavorable to the disease; and
- frequencies of disease epidemics in regions favorable to the disease once the pathogen is established.

Theoretically, predictions of disease distribution and periodical occurrence can be made by linking pathogen biological parameters to climatic databases (e.g. Strand 2000). The recent re-emergence of some diseases, such as wheat scab and soybean *Sclerotinia* stem rot in the north-central region of the USA, also indicates the possibility of cyclic patterns of these diseases. Long-term dynamics of diseases are associated with climatological events, which affect biological events of a plant pathogen. If relationships between response of an assessed disease and climate dynamics are developed, one could use the relationships to predict the periodicity of the disease using long-term climatological data as driving variables in computer models (Yang 2003). A risk assessment for soybean sudden death syndrome was conducted using CLIMAX, a computer software developed by CSIRO (Sutherst and Maywald 1999), with disease parameters generated from experiments conducted in controlled conditions (Scherm and Yang 1999).

For assessment of drought for example, an index called index of moisture adequacy is used. It is the percentage ratio of actual evapotranspiration to potential evapotranspiration. Usually for agricultural drought assessment the water balance computations are carried out on daily or weekly basis. Any period more than a week may not provide a realistic picture of water stress (Sastri 2007). A climatic water balance approach was made by Saha and Sarkar (2005) for the assessment of climatic risk involved in growing rainfed rabi crops in different agroclimatic zones of West Bengal, India. Drought, water logging and cool summer are related not only to climatic factors such as precipitation, temperature and aridity, but also to conditions of the earth's surface such as landform, soil type and so on. Moreover, since the greater the frequency of drought, water logging and cool summer disaster, the greater their probability, the frequency of drought occurrence can reflect the probability of drought disaster occurrence (Zhang 2004; Zhang et al. 2004). Therefore a Potential Danger Index of Agrometeorological Hazards (PDAH) and a Frequency of Agrometeorological Hazards Occurrence (FAHO) were used to identify and assess agrometeorological hazards. The following model is used to calculate PDAH:

$$\mathrm{PDAH} = \mathrm{PDAH_d} + \mathrm{PDAH_w} + \mathrm{PDAH_c}$$

where $\mathrm{PDAH_d}$, $\mathrm{PDAH_w}$ and $\mathrm{PDAH_c}$ denote this index for drought, water logging and cool summer, respectively. PDAH comprehensively corresponds to the degree of the potential danger of agrometeorological hazards, that is, the higher PDAH, the higher the potential danger degree of agrometeorological hazards (Zhang et al. 2005).

A probabilistic drought risk assessment model was outlined by Priya (2008), that included hazard, vulnerability and economic modules. The hazard module included stochastic events (those events based on probability of seemingly random data) from the characteristics of historical events using simulation techniques. The probabilistic drought risk model in the form of a weather generator was used to further analyze and quantify the impact of potential future drought in the state, and to compute direct losses including probable maximum and average annual losses. The vulnerability module helped quantify the damage caused to each crop due to weather hazard. The agrometeorological model was used to analyze the impact of drought on crops. Analysis included daily time step weather, rainfall distribution and intensity and also deficiencies in surface and sub-surface water supplies and soil moisture. Macroeconomic and financial modules were developed to assess the impact on various sectors of the state economy, and the fiscal implications to the state budget (see also Box III.2.22). This module also included suggestions on cost-effective risk financing and risk transfer arrangements.

A time series of wheat yields was sorted into ascending order and categorized into five percentile groupings (i.e. 20th, 40th, 60th and 80th percentiles) for each shire (county) across NSW ($\sim$100 years). Five time series of climate data (which are aggregated daily data from the years in each percentile) were analyzed to determine the period that provides the greatest climate risk to the production system. Once this period had been determined, the risk was quantified in terms of the degree of separation of the time series conditioned on the productive unit. This risk quantification could be mapped at a shire level for different times of the season to further the understanding of the degree of risk currently being managed across different spatial units, within the current climatic conditions (Weather Fair 2007).

References

Kates RW, Kasperson JX (1983) Comparative risk analysis of technological hazards (a review). Proceed Nat Acad Sci USA 80:7027–7038

Maracchi G, Capecchi V, Marta AD, Orlandini S (2006) Weather and climate monitoring for food risk management. Meteorol Appl 13:55–59

Priya S (2008) Modeling agricultural risk. http://www.vector1media.com/article/feature/modeling-agricultural-risk/

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties-regional perspectives: Asia. In: Sivakumar MVK, Motha R (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 53–69

Rivero Vega RE (2008) Workbook of climate change impacts assessments in agriculture. Basic knowledge, methodologies and tools. Cuban Institute of Meteorology/Caribbean Community Climate Change Centre. Available on the INSAM website (www.agrometeorology.org) directly from the home page

Rotter R, Keulen H Van (1997) Variations in yield response to fertilizer application in the Tropics: II. Risks and opportunities for smallholders cultivating maize on Kenya's arable land. Agric Syst 53:69–95

Saha A, Sarkar C (2005) An assessment of climatic risk involved in growing rainfed rabi crops in different agroclimatic zones of West Bengal. J Agromet 7:36–43

Sastri ASRAS (2007) Agricultural droughts: concepts, assessment and management. In. SERC School on Agricultural drought: aspects of micrometeorology. CRIDA, Hyderabad, p 74

Scherm H, Yang XB (1999) Risk assessment for sudden death syndrome of soybean in the north-central United States. Agric Syst 59:301–310

Singh S, Rao VUM, Singh D (2000) Global warming and world food security. In Singh A (ed) Resource management for sustainable agriculture. CCS HAU Hisar and MMB New Delhi, pp 251–257

Singh S, Brunini O, Singh D, Abramides PG, Rolim G, Pântano AP, Blain GC, Brunini APC, Ribeiro RV (2008) Online outreach of integrated weather based agricultural information system for sustainable agriculture through regional approach. Agrometeorological Series/2008/IAC/CIIAGRO-1, Campinas, Sao Paulo, 12pp

Sivakumar MVK (2006) Climate prediction and agriculture: current status and future challenges. Clim Res 33:3–17

Stigter CJ (2004) The establishment of needs for climate forecasts and other agromet information for agriculture by local, national and regional decision-makers and users communities. In: Applications of Climate Forecasts for Agriculture. Proceedings of the RA I (Africa) Expert Group Meeting, Banjul, December 2002. AGM-7/WCAC-1, WMO/TD-No. 1223, WMO, Geneva, pp 73–86

Strand JF (2000) Some agrometeorological aspects of pests and disease management for the 21st century. Agric For Meteorol 103:73–82

Sutherst RW, Maywald GF (1991) Climate modeling and pest establishment. Plant Prot Quar 6:3–7

Weather Fair (2007) Quantifying climate risk – the starting point. www.greenhouse2007com/downloads/papers/071004_FairweatherAbstract.pdf

WMO (2006) Drought monitoring and early warning: concepts, progress and future challenges. Brochure prepared by White D. WMO 1006, Geneva, 24pp

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by Stigter CJ. WMO, Geneva, in press

Yang XB (2003) Risk assessment: concepts, development and future opportunities. Plant Management Network. http://www.plantmanagementnetwork.org/pub/php/review/2003/concepts/

Zhang Jiquan (2004) Risk assessment of drought disaster in the maize-growing region of Songliao Plain, China. Agric Ecosyst Environ 102:133–153

Zhang Jiquan, Okada N, Tatano H, Hayakawa SJ (2004) Damage evaluation and regionalization of agro-meteorological disasters in the maize-growing region of Songliao Plain, China: case study of Lishu area of Jilin Province. Natur Haz 31:209–232

Zhang Jiquan, Hayakawa S, Zhou Daowei, Zhang Hui (2005) Risk assessment and regionalization of agro-meteorological hazards in Jilin Province, China. J Agric Meteorol 60:921–924

III.2.5.(δ) Designing and Communicating Improvements in Farm Applications of Risk Information Products: Monocropping

Kees Stigter

Risk information products are building stones of agrometeorological services as for example shown for various forms of land degradation in Africa by Stigter et al. (2005). This picture was drawn even for Africa as early as more than 10 years ago (Olufayo et al. 1998).

To design improvements in farm applications of risk information products in agrometeorology, a questionnaire/interview approach is necessary to know the present status of such applications and to make improved assessments of farmers' needs (e.g. Abdalla et al. 2002; Onyewotu et al. 2003; Stigter 2007a). The theory was discussed in Stigter et al. (2005). In this same context Stigter et al. (2008) state that after having heard so many examples in China now, it would be very helpful if studies were made into the efficiency of the information channels and the opinion of farmers on the services and these channels (look at the example in Box III.2.23). And also on eventual alternatives or additions in services and information channels, in the ways suggested by the work of Stigter et al., as presented in the CAgM workshop in New Delhi in 2006 (Stigter et al. 2007).

Jagtap and Chan (2000) believed that for Africa and Asia more emphasis had to be placed on research that will help farmers and governments better cope with expected increases in climatic risks. For agrometeorology Gommes (2001, 2003) showed the way for response farming in which the resulting advice (best management decisions) will be retransmitted to individual farmers though the agricultural extension services or broadcasting.

Stigter (2007a) exemplified ways to bridge the gaps between scientific (in this case disease) risk information products from weather services, universities or research institutes and farmers as decision makers with their own experiences. Any agrometeorological service so detected or established with a target group of farmers through certain risk communication channels, improved in pilot projects, should be considered for upscaling (Stigter 2007a).

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_25,

Box III.2.23

Stigter et al. (2008) reported on an agrometeorological service of refined agro-climatic zoning used for planning of growing navel oranges, and protection advisory services after planting, in Jiangxi Province, southern China. More details are in Sect. II.C.V. In a climatic study, with a grid size of 1 ha, of Guanzhou County, the decision for areas being suitable or unsuitable for the growth of navel oranges was taken using the yardstick of degree days (over the base of 10°) of higher than 5,500 over the whole year and a minimum winter temperature higher than –5 °C. This resulted in the actual unsuitability of all areas over 300 m. The this way determined "suitable area map" was fine tuned in very suitable, suitable and less suitable areas, using April to October sunshine hours and rainfall totals in average years. This planning was then carried out by the County Department of Fruits, that operates parallel to the Department of Agriculture and advised farmers accordingly, using subsidies in areas deemed suitable, so where the risks were acceptable.

Another part of this case study are the advisory studies related to protection from bad weather. These days, weather forecasts and such advisory services are discussed daily on cable TV, to which all farmers can listen, while some also get SMS messages. As a recent example it was indicated that in August/September 2008 there was a drought in the important period of fruit expansion. So normally irrigation will be required. However, a nearby typhoon with much rain for the area was forecasted, so an advice was given not to irrigate. Heed was taken to this message and a lot of water and efforts was saved by not irrigating, as advised.

Irrigation with impounded water, that can be seen available everywhere, is generally also done as protection to cold (in dry weather). Fire and related smoke can be used for protection from a forecasted late spring frost or early autumn frost (see also Wei 2008, detailed in Sect. II.3). In rarer years with cold wet weather, actively shedding snow or knocking ice off branches and covering young trees with straw or using it at the base helps, but it occurs less because of the planning from the earlier discussed mapping.

Weather forecasts are also given if weather is too windy for spraying. For all operations, forecasts are given when adjustment from normal procedures is advisable, along the earlier mentioned risk information channels (Stigter et al. 2008). These are examples of vulnerabilities to hazards that can be seriously reduced by temporary or permanent measures leading to impact reduction (e.g. Rathore and Stigter 2007).

This should be done through the development of training modules for extension intermediaries (see also Part I) – working at the institutions concerned or along the risk communication channels established (Stigter 2009) – to be used in Farmer or Climate Field Classes (Stigter 2007b; Winarto et al. 2008).

References

Abdalla AT, Stigter CJ, Gough MC, Mohamed HA, Mohammed, AE (2002) Underground sorghum storage in cracking clay needs shallow pits, chaff linings and wide caps. Trop Sci 42:57–64

Gommes R (2001) What can modern agricultural meteorology do for the subsistence farmers? FAO International workshop on farm radio broadcasting. Information & communication technologies (ICTs) serving farm radio: new contents, new partnerships. http://www.fao.org/docrep/003/x6721e/x6721e25.htm

Gommes R (2003) Agrometeorological policy between necessity and fashion. Newslett Eur Soc Agron 25:4pp

Jagtap SS, Chan AK (2000) Agrometeorological aspects of agriculture in the sub-humid and humid zones of Africa and Asia. Agric For Meteorol 103:59–72

Olufayo AA, Stigter CJ, Baldy C (1998) On needs and deeds in agrometeorology in tropical Africa. Agric For Meteorol 92:227–240

Onyewotu LOZ, Stigter CJ, Abdullahi AM, Ariyo JA, Oladipo EO, Owonubi JJ (2003) Reclamation of desertified farmlands and consequences for its farmers in semiarid northern Nigeria: a case study of Yambawa rehabilitation scheme. Arid Land Res Manag 17:85–101

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties-regional perspectives: Asia. In: Sivakumar MVK, Motha R (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 53–69

Stigter K (CJ) (2005) Building stones of agrometeorological services: adaptation strategies based on farmer innovations, functionally selected contemporary science and understanding of prevailing policy environments. J Agric Meteorol (Japan) 60:525–528

Stigter CJ (2007a) Agrometeorological services in the context of climatic aspects of coping with crop disease risk. Paper Presented at the APN Scoping Meeting of the Project "Climate and Crop Disease Risk Management: An International Initiative in the Asia-Pacific Region", Hyderabad, 6–10 November. Report of the Workshop, APN, Kobe, no pages

Stigter CJ (2007b) An account of visiting those involved in climate field schools in Indonesia. Available at the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology"

Stigter CJ (2009) Training intermediaries. Chapter 6.4 In: Guidelines for curricula in agricultural meteorology. Supplement No. 2 to "Guidelines for the education and training of personnel in meteorology and operational hydrology", Vol. 1, WMO 258, Geneva. http://www.wmo.int/pages/prog/etr/documents/258_vol1_Supp_2_1.pdf

Stigter CJ, Oteng'i SBB, Oluwasemire KO, Al-amin NKN, Kinama JM, Onyewotu LOZ (2005) Recent answers to farmland degradation illustrated by case studies from African farming systems. Ann Arid Zone 44(3):255–276

Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi YM (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 171–190

Stigter K, Xie Yuanyu, Liao Zhihui, Rao Qiusheng, Li Yingchun, Zheng Dawei, Wang Shili, Ma Yuping (2008). Recent identification of two agrometeorological services in Jiangxi Province, Southern China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology"

Wei Yurong (2008) Frost Forecast Service of Inner Mongolia in 2007. Available at the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology"

Winarto YT, Stigter K, Anantasari E, Hidayah SN (2008) Climate Field Schools in Indonesia: coping with climate change and beyond. Low Ext Input Sust Agric (LEISA) Mag 24(4):16–18

III.2.5.(ε) Improving Coping Strategies with Weather and Climate Risks in Agricultural Production, Including the Improved Use of Insurance Approaches: Monocropping

Kees Stigter

Improving coping strategies with weather and climate risks in monocropping very often demands the use of science in reducing limiting production factors (e.g. Fischer et al. 2002; ARS 2006; Sivakumar and Motha 2007; Stern 2007). One initiative are the Land Allocation Decision Support Systems (Rivington et al. 2006; LADSS 2007), that assist in investigations of policy impacts and environmental change impacts on land-use systems.

PASOLAC (Programa para la Agricultura Sostenible en las Laderas de América Central), operating in Nicaragua, Honduras and El Salvador since 1992, aims to increase agricultural productivity of hillside plantations through improved soil and water management (Scott 2000). The National Meteorological Services Agency in Ethiopia draws on local knowledge of the two rainy seasons, as well as on forecasts by international organizations (Orlove and Tosteson 1999).

Options for soil and rainwater conservation, integrated nutrient and crop management, development of water resources, watershed and alternate land use systems were examined for Asia and the Pacific by FAO (2001). However, without the knowledge or resources the poor may have to rely on ad-hoc and unsustainable responses, reducing their resilience to a range of shocks and stresses (Adger et al. 2003; DFID 2004a). This is why insurances are also for them considered an alternative (DFID 2004b). Provision of an index-based weather insurance directly to smallholders in Malawi is discussed as an example in Box III.2.24.

Box III.2.24

Helmuth et al. (2007) describe a pilot project in Malawi, southern Africa, that is testing a new way of dealing with drought risk: provision of index-based

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_26,

weather insurance directly to smallholders. Here contracts are written against an index that describes an established relationship between, for example, lack of rainfall and crop failure, ideally verified by long historical records of both rainfall and yields. If rainfall turns out to be low, failing below an agreed trigger point, the farmers receive payouts. But whether the insurance pays out or not, farmers still have the incentive to make productive management decisions.

The main advantage over crop insurance is that, when rainfall is low enough to cause crops to fail, insurers will pay out to farmers quickly, so that farmers do not need to sell off their assets (equipment/animals) to survive. The money will see them through the drought period, and they will then be able to continue farming when the rains resume. IRI was asked to provide technical support, to design and evaluate the insurance product.

The NMHS of Malawi is the source of the climate and weather related data and expertise, essential for the design and implementation of the insurance scheme. The data needed include historical rainfall and evapotranspiration, together with soil characteristics and agronomic information. Needed for implementation are reliable monitoring and timely reporting of rainfall, since these are the basis for determining payouts.

Two micro-financing institutions are participating as loan providers. The first task was to select the commodity on which to test the concept. Obviously the main criterion had to be drought sensitivity, but other criteria were also important, such as level and costs of inputs needed, the existence of an organized marketing system, the value of the crop and the crop's suitability for smallholder farmers.

Groundnut, which scored well against most of these criteria, was chosen for the pilot phase in 2005. Consultations with the NMHS, the extension service, and farmers suggested that farmers within 20 km of a station would experience roughly the same rainfall patterns as the station itself. Thus, during the pilot phase, only farmers within this radius were insured. The insurance contracts were designed to pay out if the rainfall data from the nearest meteorological station showed a deficit at one or more of four critical stages of the growing season, that is before sowing and during establishment, flowering and maturation (Helmuth et al. 2007).

A logical improvement would be obtained when trustable independent on-farm rainfall measurements could be introduced, like that was done in the Mali agrometeorological pilot projects and has also just started in Gunungkidul, Wonosari, near Yogyakarta, Central Java, Indonesia, with alumni of a Climate Field School (Winarto et al. 2008).

Some farmers in the USA currently feel comfortable in dealing with commodity brokers and the use of hedging tools that can reduce risk in their farming operations, and they believe that these methods can increase farm income (Hanson and

Pederson 1998). ITF (2006) is introducing the use of index-based weather insurance to deal with weather risk in developing countries. The same approach is described in UNESA (2007). A special part of Sivakumar and Motha (2007) also deals with weather risk insurance for agriculture.

References

Adger WM, Huq S, Brown K, Conway D, Hulme M (2003) Adaptation to climate change in the developing world. Prog Dev Stud 3:179–195

ARS (2006) Global Change National Program 204 FY2006 Annual Report. United States Department of Agriculture. http://www.ars.usda.gov/SP2UserFiles/Program/204/NP2042006AnnualReport.doc

DFID (2004a) The impact of climate change on the vulnerability of the poor. DFID Key Sheet on Climate Change and Poverty no 3. http://www.dfid.gov.uk/pubs/files/climate change/3vulnerability.pdf

DFID (2004b) Adaptation to climate change: can insurance reduce the vulnerability of the poor? DFID Key Sheet on Climate Change and Poverty no 8. http://www.dfid.gov.uk/pubs/files/climatechange/8insurance.pdf

FAO (2001) Report of the FAO Asia-Pacific Conference on Early Warning, Prevention, Preparedness and Management of Disasters in Food and Agriculture, Chiangmai. Annex XIV, APDC/01/10. Developing farming systems and best practices for drought-prone areas. http://www.fao.org/DOCREP/005/AC120E/AC120e15.htm

Fischer G, Shah M, van Velthuizen H (2002) Climate change and agricultural vulnerability. IIASA, Laxenburg, Austria. http://www.iiasa.ac.at/Research/LUC/JB-Report.pdf

Hanson DK, Pederson G (1998) Price risk management by Minnesota farmers. University of Minnesota Extension Newsletter 691. http://www.extension.umn.edu/newsletters/ageconomist/components/ag237-691b.html

Hellmuth ME, Moorhead A, Thomson MC, Williams J (eds) (2007). Climate risk management in Africa: learning from practice. International Research Institute for Climate and Society (IRI), Columbia University, New York, 105pp

ITF (2006) The International Task Force on commodity risk management in developing countries. Weather risk. http://www.itf-commrisk.org/itf.asp?page=3

LADDS (2007) Land Allocation Decision Support System. http://www.macaulay.ac.uk/LADSS/

Orlove BS, Tosteson JL (1999) The application of seasonal tointerannual climate forecasts based on el niño-southern oscillation (enso) events: lessons from Australia, Brazil, Ethiopia, Peru and Zimbabwe. IIS, University of California, Berkeley, Working Paper 99-3. http://globetrotter.berkeley.edu/EnvirPol/WP/03-Orlove.pdf

Rivington M, Matthews K, Buchan K, Miller D (2006) An Integrated Assessment approach to investigate options for mitigation and adaptation to climate change at the farm scale. http://www.macaulay.ac.uk/LADSS/papers/NJF_adaption_crops_cc.pdf

Scott L (2006) Chronic poverty and the environment: a vulnerability perspective. CPRC WP 62, ODI, London. http://www.chronicpoverty.org/pdfs/62Scott.pdf

Sivakumar MVK, Motha R (2007) Managing weather and climate risks in agriculture. Springer, Heidelberg/Berlin, 503pp

Stern N (2007) The economics of climate change. Cambridge University Press, Cambridge, 692pp

UNESA (2007) Developing Index-based insurance for agriculture in developing countries. UNESA Sustainable Development Innovation Brief No 2. http://www.un.org/esa/sustdev/publications/innovationbriefs/no2.pdf

Winarto YT, Stigter K, Anantasari E, Hidayah SN (2008) Climate field schools in Indonesia: coping with climate change and beyond. Low Ext Input Sust Agric (LEISA) Mag 24(4):16–18

III.3 Applied Agrometeorology of Multiple Cropping

III.3.1 Strategic Use of Climate Information

III.3.1.(a) Combating Disasters: Multiple Cropping

Kees Stigter

Case studies of combating disasters (as the forced marriages between hazards and vulnerabilities, see Sect. III.2.1.(a)) in a multiple cropping context must start around traditional agro-ecological balances and diversity purposely kept (e.g. Singh 1996; Ramprasad 1999; Upawansa 2003; Dessein 2005; Shankar 2005) or (re)designed (e.g. Altieri 1996; Maita and Verweij 1996; Riggs 2003; Onduru et al. 2003; Satheesh 2005). The literature on Low External Input Sustainable Agriculture and that on Endogenous Development and Indigenous Knowledge is full of such examples and only an arbitrary range of case studies is presented.

The purpose also here remains to increase with farmers as decision makers the awareness on potential climate and climate (change) related hazards and their mitigation, now with the advantages of reduced vulnerability from multiple cropping and related cultural measures. In the above quoted literature from Africa, Latin America, India, China and other parts of Asia, this is for example explicitly related to de- and afforestation (e.g. Riggs 2003; Shankar 2005), deficient soil moisture (e.g. Shankar 2005) and nutrients (e.g. Onduru et al. 2003; Satheesh 2005), erosion (e.g. Maita and Verweij 1996; Riggs 2003; Onduru et al. 2003), frost (e.g. Altieri 1996), pests and diseases (e.g. Riggs 2003; Shankar 2005), drought (e.g. Altieri 1996; Satheesh 2005; Shankar 2005), drought and flood forecasting (Upawansa 2003), climate change (e.g. Shankar 2005) and loss/reestablishment of water impoundment (Maita and Verweij 1996), biodiversity (Singh 1996; Ramprasad 1999; Satheesh 2005), homegarden (microclimate) properties (Singh 1996; Dessein 2005) and sustainability in general (e.g. Singh 1996).

Davies (2000), discussing potentials and pitfalls of endogenous development, states that indigenous knowledge represents a precious, invisible link between a region, its resources and the store of experiences nurtured by the specialists in the community. New techniques should serve to describe, analyze, validate and classify the beliefs and processes of the traditional knowledge system (e.g. Baldy and Stigter 1997; Davies 2000; Stigter et al. 2005). Within the appropriate policy environments,

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_27,

traditional adaptation strategies and contemporary knowledge systems are jointly needed to create public and private services combating disasters (Stigter 2002, 2005, 2007). A good example of this in combating the disaster of land degradation in Nigeria is given in Box III.3.1, where traditional knowledge on intercropping systems was the starting point of proposed improvements in these matters.

Box III.3.1

Intercropping components adopted by farmers in northern Nigeria are grown at low densities, to minimise risks and exploit resources in a good cropping season (Oluwasemire et al. 2002). High year-to-year variability of rainfall, serious deep percolation and high wet soil evaporation losses are additional stresses. When the rainfall was below normal, the intercropping systems showed better water use efficiency than all sole crops, with the exception of the case of millet with inorganic fertilizer side dressing, due to millet dominance exerted by earlier planting and heavy tillering. All the crops sown sole and intercropped rooted beyond 1 m in the loose sandy soil. Sorghum root production was greater than for millet, while both cereals produced greater root densities than cowpea. Overlap of the roots of component crops suggests competition for resources. Cowpea produced greater root densities and achieved deeper rooting when intercropped with millet and/or sorghum than sole, suggesting adaptation and competitive ability under intercropping. Rooting depths of crops were shallower in a relatively wet season than when water was limiting. Root densities and root proliferation of the cereals below the surface layer were much higher in low fertility soils than when nutrients were readily available. An answer with designing improved cereal/legume intercrop systems in the Nigerian arid and semi-arid zones should include genetically superior crop cultivars and the manipulation of the component densities along with the improvement of microclimatic variables. An amelioration of the traditionally preferred rainfed millet/cowpea and sorghum/millet/cowpea intercrop systems may involve a reduction in plant density of the tillering and faster dry matter accumulating millet component, while the low growing and ground covering cowpea component density is increased. The results learn that abundant organic manure in combination with agrometeorological services on intercrop manipulation related microclimate improvements may control near surface land degradation in northern Nigeria under acceptable sustainable yields (Oluwasemire et al. 2002; WMO 2010).

References

Altieri M (1996) Indigenous knowledge re-valued in Andean agriculture. ILEIA Newslett 12(1):7–8. http://www.leisa.info/index.php?url=show-blob-html.tpl& p[o_id]=12144&p[a_id]=211& p[a_seq]=1

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Davies G (2000) Endogenous development: potentials and pitfalls. Compas Newslett 3:40–41. http://www.compasnet.org/english/dloadz/nl3/link19.pdf

Dessein J (2005) Between the traditional and the capitalist modes of farming. http://www.compasnet.org/english/dloadz/nl8/dessein38-40.pdf

Maita JC, Verweij MJ (1996). Water means life. ILEIA Newslett 12(1):12. http://www.metafro.be/leisa/1996/12-1-12.pdf

Oluwasemire KO, Stigter CJ, Owonubi JJ, Jagtap SS (2002) Seasonal water use and water yield of millet based cropping systems in the Nigerian Sudan Savanna near Kano. Agric Water Manag 56:207–227

Onduru D, Muchena F, Gachimbi L, de Jager A (2003) Farmer field school on nutrient management. Low Ext Input Sust Agric (LEISA) Mag 19(4):26–27

Ramprasad V (1999) Women and biodiversity conservation. Compas Newslett 2:24–25. http://www.compasnet.org/english/dloadz/nl2/link8.pdf

Riggs P (2003) Agroecological restoration in Guangdong. Low Ext Input Sust Agric (LEISA) Mag 19(4):24–25

Satheesh PV (2005) Community food sovereignty. Compas Mag 8:20–22. http://www.compasnet.org/english/dloadz/nl8/sateesh20-22.pdf

Shankar KJNG (2005) Strengthening tribal economies through endogenous development. Compas Mag 8:32–35. http://www.compasnet.org/english/dloadz/nl8/idea32-35.pdf

Singh V (1996) Diversity in mountain agriculture. ILEIA Newslett 12(1):16–17. http://www.leisa.info/index.php?url=show-blob-html.tpl& p[o_id]=12149&p[a_id]=211& p[a_seq]=1

Stigter K (2002) Opportunities to improve the use of climate forecasts. Asian Climate Training Workshop on "Climate Information Applications", Asian Disaster Preparedness Center (ADPC), Bangkok, Bullet points + 18 pages, available on CD-ROM

Stigter K (CJ) (2005) Building stones of agrometeorological services: adaptation strategies based on farmer innovations, functionally selected contemporary science and understanding of prevailing policy environments. Paper Presented as the Opening Keynote Lecture at the International Symposium on Food Production and Environmental Conservation in the Face of Global Environmental Deterioration (FPEC, 2004), Fukuoka. J Agric Meteorol (Japan) 60:525–528

Stigter CJ (2007) From basic agrometeorological science to agrometeorological services and information for agricultural decision makers: a simple conceptual and diagnostic framework. A Guest Editorial. Agric For Meteorol 142:91–95

Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005) Using traditional methods and indigenous technologies for coping with climate variability. Clim Change 70:255–271

Upawansa GK (2003) Ancient farming and modern science. Compas Mag 9:35–37. http://www.compasnet.org/english/dloadz/nl6/eco35-37.PDF

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by Stigter CJ. WMO, Geneva, in press

III.3.1.(b) Selection Processes of (Changes in) Land Use and Cropping Patterns: Multiple Cropping

Emmanuel Ofori and Nicholas Kyei-Baffour

Selection processes of (changes in) land use and cropping patterns could be discussed under socio-economy, climate variability and change, technological innovations and land degradation (ecologically). Socio-economic factors will include changes in population growth as a result of migration, expansion into new and uncropped lands or unused lands. Farmers would grow a certain type of crop for several reasons.

Very important is the issue of climate variability and change. Climate change is likely to bring new weather patterns that farmers are unfamiliar with and these changes need reactions with some level of sophistication beyond the capacity of the farmers and even traditional institutions. Some lands may get out of production due to land degradation from increased extreme events such as flooding and drought or intense land use and nutrient mining. Shifts in rainfall patterns and other climate factors may also play a role. Such lands may have to get other use or become suitable for other crops. Climate determines the type of crop to grow and how the available resources can be used. The available resources (labour, water and soil) will determine the farming system.

Cropping elements and cropping sequences that would fit into a given climate system must be selected (e.g. Brown 2003). Technological factors include access to information, improved crop varieties, plant protection measures, mechanization and irrigation facilities. Technological innovation may also allow for double cropping in areas that used to be under single cropping as a result of the introduction of new crop varieties that will suit the environment (e.g. modern rice varieties of short growing periods have allowed for the change from single cropping to double cropping systems). According to Shresta (2006) introduction of new agricultural technology and rapid urbanization have encouraged farmers in the Kathmandu Valley to change their cropping patterns from traditional low value crops to new high value crops.

E. Ofori (✉)
Agricultural Engineering Department, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
e-mail: oforiegh@yahoo.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_28,

Prevailing global circumstances resulting from rising crude oil prices, increasing prices for agricultural inputs, weather related events of climate change and variability, diversion of crops and crop land for biofuel production, competing use of land other than for agriculture have placed a strain on world food production and food security. Due to environmental conditions and concerns, in many regions most of increased food production is not likely to come from expanding the available land (e.g. Von Braun 2007).

The solution to improved crop productivity does not only rely on mechanized rotational monocropping systems used in developed countries such as North America and Western Europe, but also on the polyculture cropping systems traditionally used in developing countries such as Africa and Latin America (Francis and Adipala 1994). According to LEISA (2008), a new debate is emerging across the world about the future agriculture at a time of food, fuel and financial crises. We need to foster an agriculture that is inclusive, multifunctional, and built on principles of resilience that are crucial in the process of adapting to climate change. We need farming systems that will ensure increased food security, decrease environmental impact, respond to climate change and that provide management alternatives that will enhance natural resource use, provide stable and high returns to the farmer, so that there is trade-off between agricultural benefits and environmental costs (see also Palmer 2008).

The major cause in favor of selecting multiple cropping systems is the fact that it involves integrating crops using space, climate, soil resources and labor more efficiently (e.g. Stigter and Baldy 1989; Baldy and Stigter 1997). The reasons can be biophysical, agronomic and socio-economic. Biophysical reasons include better utilization of environmental factors, greater yield stability in variable environments and soil and other conservation practices (Box III.3.2). An agronomic reason is when one crop complements the other, like the growing of nitrogen fixing crops to supply nutrients to the soil and addition of crop residue to the soil. Socio-economic reasons include the magnitude of inputs and outputs and their contribution to the stabilization of household food supplies (e.g. Beets 1982). Other socio-economic factors such as those related to round the year food availability for the farmer's household, sustained income and livelihood, marketability and prices are also important. It can also provide for other household needs such as fuel, fibre, labor utilization, fodder when crop production is blended with agroforestry, animal production and other farming enterprise (beekeeping, aquaculture) on a sustainable basis.

Box III.3.2 (Contributed by Kees Stigter)

Stigter and Baldy (1993) discuss a land use and cropping pattern selection with early and late intercropping in coconut plantations in their attempt to illustrate that in such cropping "active" and "passive" services are mutually rendered with respect to microclimate. They prove that from observations in classical literature such as Nelliat et al. (1974), Nair and Balakrishnan (1977), Nair, quoted in GTZ (1984), Liyanage et al. (1984), Palaniappan (1985), Jamaluddeen and Jacob as well as Sefania et al., both quoted by Steiner (1986), and Smith, quoted in Carls (1988), it may be observed that both "passive" and "active" services are rendered with respect to the microclimate. There is the "passive" service of sharing radiation with the companion crop by the coconut palm in its youngest and oldest stages but the "active" service of resource conservation by suppressing competitive weeds by its shade.

Admittedly some care has to be taken in using "active" and "passive" here, as for companion crops that cannot stand high radiation loads, the shade service becomes an "active" one! There is the mutual "passive" service of leaving water in the different horizons to share, but the "active" service of reducing evaporation of the companion crop through the change of the microclimate as a whole (radiation, air movement, temperature, humidity, perhaps carbon dioxide). While part of this change contributed by the companion crops "actively" serves the yield level of coconuts, through whatever mechanisms. In comparison with other combinations, "passively" air space appears most efficiently used as a resource by coconut intercropping, while the coconut shade "actively" protects companion crops by reducing insect and disease attacks, for example in cocoa. Of course different management systems give different results (Stigter and Baldy 1989) and these details are left out in this reviewing illustration (Stigter and Baldy 1993).

Multiple cropping systems are prevalent in many parts of the world (e.g. Andrews and Kassam 1976) and also farmers in the temperate regions have for example used alternating strips of corn and soybeans (e.g. Sullivan 2003). However, basically multiple cropping is a traditional method of intensive farming in warm climates attempting optimal use of land, water, nutrients, labour, solar radiation and other climatic factors. Multiple cropping is a system of farming that is suitable for risk aversion of total crop failure in dryland farming, a system of (associations of) local or other varieties of food and cash crops (including trees) proven to be suitable.

Multiple cropping can be done with annual food crops, perennial crops (such as cotton), fodder crops, tree crops and energy crops. It offers a respite for food production in the face of the current food and energy crises; it offers solutions to food security in agricultural production in advanced technologies and also for small holder resource-poor farmers in developing countries. If the suitable resources are available (climate, soil, water and labour), multiple cropping can provide a year-round supply of cereals, fruits, meat, biofuels, vegetables and enough family income.

Advantages of multiple cropping systems in comparison to monocropping systems are insurance against crop failure, more total yield per unit area, optimum use of available resources (soil, sunlight, water and labour), soil fertility sustenance and more economic returns to the farmer (Walker et al. 2011). From a small-scale resource poor farmer perspective in the developing countries, multiple cropping is more a strategy of risk aversion, livelihood sustainability, better nutrition, crop diversification. In their selection of (changes in) land use and cropping patterns, according to Rosset (1999), small farmers are more likely to intercrop various crops on the same field, plant multiple times during the year, and integrate crops, livestock and even aquaculture, making much more intensive use of space and time. To the small scale resource-poor farmer, multiple cropping serves to enhance risk avoidance regarding income, yield and ecological balance. From a commercial or large scale agriculture perspective in the developed countries, multiple cropping is practised to gain advantage of increased land productivity, maintenance of diversity, response to the effects of climate change, disease and pests control and ecosystem health.

Microclimate modification patterns are about the mimicking of natural systems to control the environment to achieve several benefits. They are all connected in one way or the other with multiple cropping to make them effective. These are microclimate modifications to (see also Box III.3.2):

a. achieve shade and wind break;
b. get climate moderation to minimize evaporation and to reduce stress in animals to improve productivity;
c. obtain pests and diseases control (e.g. Legner 2000; Krupinsky et al. 2002);
d. achieve flood control by increasing soil infiltration characteristics.

Multiple cropping can offer many aspects of the pest/parasite habitat or environment that can be purposefully manipulated, through microclimate modifications. It is possible to stabilize the insect communities of agroecosystems by designing and constructing vegetation architectures that support populations of natural enemies or that have direct deterrent effects on pest herbivores.

Crops grown simultaneously enhance the abundance of predators and parasites, which in turn prevent the build-up of pests, thus minimizing the need to use expensive and dangerous chemical insecticides. For example, in the tropical lowlands, corn/bean/squash polycultures suffer less attack by caterpillars, leafhoppers, trips, etc., than corresponding monocultures, because such systems harbor greater numbers of parasitic wasps. The plant diversity also provides alternative habitats and food sources such as pollen, nectar, as well as alternative hosts to predators and parasites (Altieri 1999).

Crop rotation is also an important pest and disease control strategy in annual cropping systems. It is based on the principle of altering host environment with a non-host plant, thus disrupting the life cycle of the parasite. Overhead shade has a major effect on the microclimate conditions under which pests and disease organisms, their natural enemies and the crop themselves develop and its optimization is a highly efficient control strategy for many pests and parasites. Soil fertility is also important, in that the susceptibility of crops to pests and diseases is strongly affected by the availability of plant nutrients.

References

Altieri MA (1999) Enhancing the productivity of Latin American traditional peasant farming systems through an agroecological approach. Conference on "Sustainable Agriculture: New Paradigms and Old Practices?", Bellagio Conference Center, Italy. Also: http://agroeco.org/fatalharvest/articles/enhancing_prod_la_peasants.html

Andrews DJ, Kassam AH (1976) The importance of multiple cropping in increasing world food supplies. In Papendick RI, Sanchez A, Triplett GB (eds) Multiple cropping. ASA Special Publication 27. American Society of Agronomy, Madison, pp 1–10

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publ. Co., New Delhi; Science Publ. Inc., Enfield, 237pp

Beets WC (1982) Multiple cropping and tropical farming systems. Westview Press, Boulder, 156pp

Brown LR (2003) Plan B: rescuing a planet under stress and a civilization in trouble. W.W. Norton & Co., New York. http://www.earth-policy.org/Books/PB/PBch8_ss3.htm

Carls J (ed) (1988) Abstracts on intercropping, Vol. 6 (1987). GTZ, Eshborn, 275pp

Francis CA, Adipala E (1994) Tropical intercropping systems. What is their future? Afr Crop Sci J 2:131–133

GTZ (1984) Abstracts on intercropping, Vol. 1 (1982). GTZ, Heidelberg, 74pp

Krupinsky JM, Bailey KL, McMullen MP, Gossen BD, Turkington TK (2002) Managing plant disease risk in diversified cropping systems. Agron J 94:198–209

Legner E (2000) Management of the environment to favor pest control. http://www.faculty.ucr.edu/∼legneref/biotact/bc-58.htm

LEISA (2008) Dealing with climate change. An editorial. Low Ext Input Sust Agric (LEISA) Mag 24(4):4–5

Liyanage M de S, Tejwani KG, Nair PKR (1984) Intercropping under coconuts in Sri Lanka. Agrofor Syst 2:215–228

Nair PKR, Balakrishnan TK (1977) Ecoclimate of a coconut plus cacao crop combination on the west coast of India. Agric Meteorol 18:455–462

Nelliat EV, Bavappa KV, Nair PKR (1974) Muliti-storeyed cropping, a new dimension in multiple cropping for coconut plantations. World Crops 26:262–266

Palaniappan S (1985) Cropping systems in the tropics. Principles and management. Wiley Eastern Ltd., New Delhi etc., 215pp

Palmer C (2008) "Greening" agriculture in the developing world. Int J Rural Dev (Rural 21) 42(3):30–32

Rosset PM (1999) The multiple functions and benefits of small farm agriculture in the context of global trade negotiations, Institute for Food and Development Policy Brief No. 4. www.foodfirst.org

Shrestha MR (2006) Urbanisation and changes in cropping patterns at Katmandu Valley. Nepal J Sci Technol 7:113–118

Steiner KG (ed) (1986) Abstracts on intercropping, Vol. 4 (1985). GTZ, Heidelberg, 198pp

Stigter CJ, Baldy C (1989) Agrometeorology of multiple cropping systems: biomass management and the low external input African farmer. Proceedings of the 2nd ICTP/SAPAM Workshop on the Applicability of Environmental Physics and Meteorology in Africa, Addis Ababa University, ICTP/SAPAM, Ethiopia, 13pp

Stigter CJ, Baldy CM (1993) Manipulation of the microclimate by intercropping: making the best of services rendered. In: Sinoquet H, Cruz P (eds.) Ecophysiology of tropical intercropping, INRA, Paris/Guadeloupe, pp 29–44

Sullivan P (2003) Intercropping principles and production practices. National Sustainable Agricultural Information Service (13 Arkansas, AR 72702), Butte, Montana and Davis, California. http://www.attra.org/attra-pub/PDF/intercrop.pdf

Von Braun J (2007) Rising world food prices: impact on the poor. Int J Rural Dev (Rural 21) 42(3):19–21

Walker S, Stigter CJ, Ofori E, Kyei-Baffour N (2011) Intercropping and its implications for soil management. In: Hatfield JL, Sauer TJ (eds) Soil management: building a stable base for agriculture. American Society of Agronomy, in press

III.3.1.(c) The Selection of Actual Preparedness Strategies for Dealing with Climate as Adopted in Multiple Cropping

Emmanuel Ofori, Nicholas Kyei-Baffour, and Kees Stigter

Preparation for sustainable agriculture seeks to use nature as the model for designing agricultural systems that maintains diversity. Multiple cropping offers to farmers the opportunity to engage nature's principle of diversity at their farms. Among the practices that promote diversity and stability are:

a. farming enterprise diversification. Farmers diversify their crops and livestock to achieve stability of income and yield. This also helps to make savings in costs of pest control and fertilizer, as the costs can be spread out over several crop or animal enterprises;
b. crop rotation. Moving away from monoculture to polyculture with viable crop rotations breaks weed and pest life cycles, improves soil structure and provides complementary fertilization to crops in sequence;
c. integration. Integrating livestock with crops through agroforestry or more specifically silvopastoral systems also promotes diversity. Growing two or more crops on the same piece of land also enhances diversity.

Das (Personal Communication 2008) argues that competition among plants in a community or intercrop of associated plants sets in after a certain period of no interaction, when seedlings have adequate growth resources. The onset of interference occurs as plants increase in size and depend on the presence and further development of rooting systems with which resources have to be shared. The mass then begins to vary according to intensity and duration of interference. Ideally spacing of the field crops is prepared such that the plants are best sharing the available resources so that no plants die or become unproductive. Individual plants experience less than the optimal yield possible if they had unlimited resources, but as a community the yield is optimized. What one yields is the response to the preparations of these optimized production systems in relation to seed rate, plant density, fertilizer application etc.,

E. Ofori (✉)
Agricultural Engineering Department, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
e-mail: oforiegh@yahoo.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_29,

particularly also in the context of climate variability and climate change. When these are different from average, adaptations may be required for the ongoing season as a form of response farming (Stigter 2008).

Preparative measures for dealing with climate in multiple cropping are twofold. Using climate to guide in dealing with factors that limit crop productivity (see Sects. III.3.1.(g) and III.3.3.(A)) and making adjustments for the prevailing weather conditions as the cropping years progresses (see for example Sect. III.3.1.(d)). The following ones may be distinguished specifically for each (inter)crop under its field conditions:

- adjustment of cropping calendars, association of crops and rotations;
- development and promotion of high yielding varieties when risk aversion is not necessary;
- adoption of suitable varieties resistant against extremes of climate (heat, cold, drought, floods, strong winds etc.);
- water-efficient cultivars;
- cultivars with resistance to pests and diseases;
- soil conservation measures such as relationships between soil properties, topography and land management (Hoshikawa 2003);
- optimum use of fertilizers;
- promotion of water saving technologies;
- organizing availability of water for supplementary irrigation;
- promotion of drainage where flooding is a problem;
- use of microclimate management and manipulation (see Sect. III.3.1.(f));
- adoption of more sustainable agrotechnological applications;
- organizing preparedness for actually available warnings or those to be requested (e.g. Sect. III.3.1.(b) and III.3.3.(B));
- organizing farm infrastructure integrated with production planning.

In response farming with the above preparedness factors (for adjustment), climate has to be assessed historically, instantly and predictively as to the start, duration and end of the rainy seasons as well as in the frequency of dry spells and the variability of temperature. This is not different in multiple cropping compared to monocropping (see Sect. III.2.1.(c)), only more complicated and diverse (see also Sect. III.3.1.(d)).

It becomes different when we are talking about the microclimate of multiple cropping, its management and manipulation (e.g. Stigter and Baldy 1993; Stigter 1993). In their section "Overall Conclusions" in the only existing textbook on the agrometeorology of multiple cropping, Baldy and Stigter (1997) summarized these complications already as to (i) the spatio-temporal redistribution of the water of rainfall and the related water erosion and nutrient balances, (ii) wind erosion, (iii) grass, bush and crop residue fires, (iv) the energy balance and thermal and humidity regimes, (v) the above and within crop wind characteristics, with and without trees as intercrops. They also summarize there the interactions between climatic elements and multiple cropping. This serves the understanding of the above preparedness needs. The literature given there is still useful (Baldy and Stigter 1997). Multiple cropping explicitly mentioned in capacity building is exemplified in Stigter (2005) and Ministry of Foreign Affairs of Japan (2007).

Sheshagiri Rao (2008), as a farmer with research interest in ecology and agriculture in semi-arid India, makes a plea for a new paradigm of rainfed farming options in these semi arid regions. He argues from experience that in preparedness to match the increasing climate variability with even larger variability in the mix of farming options, under present conditions simple multiple cropping can roughly cope with current livelihood options. Adding high density agroforestry will considerably increase the variability that farmers prepare for. Adding livestock rearing will increase this even more (see Box III.3.3). The highest variability in climate can be covered by also adding farm based enterprises (Sheshagiri Rao 2008). Also Hay (2008) mentions for India multiple cropping as an approach decreasing the likelihood and the consequences of agricultural drought risks in increased preparedness. Agroforestry may here increase their likelihood, due to tree transpiration, but decreases their consequences. However, we then only talk about water in the surface layers, where there is competition with crops, such as in hedgerow alley cropping, while most water is in most agroforestry cases taken from deeper layers (e.g. Ong et al. 1996).

Box III.3.3

The benefit of integrating livestock production with tree/fruit and/or forage crop production for better preparedness for climate variability is that mixed cropping can be introduced whereby the land could be put to multiple uses for several obvious benefits. These are:

1. increased productivity;
2. generation of environmental services;
3. improved livelihood of farmers and rural poor.

Potential livestock choices include sheep, goat, cattle, horse, turkeys, chickens, ostriches, guinea fowl and game animals, depending on the geographical location and compatibility. In all it depends on landowner objectives but consideration must be given to increasing income, land productivity, sustainable soil use, maximum resource use and mobilization. A source of local technical assistance is essential to develop a silvopastoral system matched to local conditions and landowner objectives.

Tree pattern is an important factor for any successful silvopastoral system. Trees can be evenly distributed over the area, either in rows or clusters, and pruning or thinning must be managed. Shelter for livestock must be planned for severe weather events. Stress to livestock can be reduced through moderation of pasture microclimate that a well-planned silvopastoral system provides. There is indeed a climate stabilizing effect of trees that reduce wind and provide shade to reduce heat stress and wind chill on livestock (Klopfenstein et al. 1997).

Before a new silvopastoral system is established as preparedness, implications of merging forestry and agricultural systems should be explored thoroughly for economic and development considerations, along with local land use, zoning and cost-sharing programmes. The combinations of trees, crops and/or animals should be intentionally designed as services and managed to achieve the desired benefits whilst maintaining the soil resource base. A well-planned system must have (Walker et al. 2011):

(i) considerations of spacing. The number and size of trees should be managed for continuous even spacing that optimizes light, growing space for tree crop and fodder production. Spacing must keep in mind how it effects tree growth and competition with one another;
(ii) plant selection considerations. When considering tree and forage crop selection, consider potential markets, soil type, climate conditions, and species compatibility;
(iii) environmental considerations. How the pattern of trees affects wildlife habitat, ease of livestock handling, forage and tree growth and competition, and microclimate.

Criteria for tree crop selection (banana, mango, citrus, coconut, cashew etc.) are: marketability; quality of crop/plant; growth characteristics; rooting characteristics; drought tolerance; capability of providing the desired products and environmental benefits; light penetration; extent of ground protection by leaf litter. The forage component (beans, pulses, grasses etc.) should be a perennial crop that is suitable for livestock grazing; compatible with the site; productive under partial shade; responsive to intensive management; tolerant to heavy utilization; deliver protection of the soil from erosion and drying up; impede development of weeds; enrich soil with nitrogen; contribute to the build up of soil organic matter and humus content (Walker et al. 2011).

From the management point of view, livestock grazing should be intensively and carefully managed so that system compatibility (soil, fauna, livestock, and tree plants) is maintained. The following management tools should be considered: tree harvesting, thinning and pruning; fertilizing to improve both forage and tree production, if necessary; planting legumes for nitrogen fixation and forage production; multi-pasture use, rotating grazing and developing walkways to facilitate that; supplemental feeding to take care of anticipated adverse conditions and to allow for pasture regeneration or to avoid system vulnerability periods (tree fruiting, wet soil trampling etc.).

From the economic benefits point of view, integrating trees, forage and livestock creates a land management system to produce marketable products while maintaining long-tem productivity. Economic risk is reduced because the system produces multiple products (dairy, beef, timber, charcoal, fruit, forage), most of which have established markets. Comprehensive land utilization in silvopastoral systems provides a relatively constant income from livestock sale and selective sale of tree, timber and other products. As other economic benefits, production costs are reduced and marketing flexibility is enhanced by distributing management costs between timber and livestock components. Carbon sequestration in trees and pasture roots and soils, biodiversity and watershed protection, agrotourism and agroecotourism are other potential benefits (Walker et al. 2011).

Trees hold nutrients in an efficient, closed cycling system. Their deeper roots tap nutrients from lower soil levels that are inaccessible to forage species, and nitrogen fixing trees can raise the nutrient levels of pasture soils. Well-managed forage production provides improved nutrition for livestock growth and production. There may be supplemental nutrient-rich fodder production in the tree leaves. Fertilizer applied for forage is also used by trees, livestock manure recycles nutrients to trees and forage, grazing would control weeds, grass competition for moisture, nutrients and sunlight. Shade and reduced wind speed raise the moisture level of soils by reducing evaporation. There is reduced soil compaction due to root development. Organic matter input is increased, erosion is reduced, thereby improving soil structure and soil biological activity. Increased wildlife diversity may be expected and forage or understorey litter protects the soil from water and wind erosion.

References

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Hay JE (2008) Weather and climate extremes: risks to the agriculture sector. http://www.wamis.org/agm/meetings/worisk06/S2-Hay_WORISK.pdf

Hoshikawa K (2003) Multiple cropping system of mountain-slope agriculture in the central part of Japan. International Symposium Alternative Approaches to Enhancing Small-Scale Livelihoods and Natural Resources Management in Marginal Areas – Experience in Monsoon Asia – UNU, Tokyo, 29–30 October. http://www.unu.edu/env/plec/marginal/proceedings/HOSHIKAWA.pdf

Klopfenstein NB, Rietveld WJ, Carman RC, Clason TR, Sharrow SH, Garrett G, Anderson B (1997) Silvopasture: an agroforestry practice. Agroforestry Notes (USDA-NAC) 8, USDA Forest Service, 4pp. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1005&context=agroforestnotes

Ministry of Foreign Affairs of Japan (2007) International cooperation for adaptation to climate change in developing countries (Recommendations by experts committee). Dialogue on long-term cooperative action to address climate change by enhancing implementation of the Convention. Third Workshop, Bonn, 16–17 May 2007. Dialogue Working Paper 5 (2007) Submission from Japan. UNFCCC, Bonn. unfccc.int/files/meetings/dialogue/application/pdf/wp5-japan.pdf

Ong CK, Kinama J, Chiti R, Gichuki F, Stigter CJ, Ng'ang'a JK (1996) Agroforestry for soil and water conservation in drylands. In: Mugah JO (ed) People and institutional participation in agroforestry for sustainable development. First Kenya Agroforestry Conference, NASC and ICRAF, Nairobi, pp 297–308

Sheshagiri Rao PR (2008) Whose decision is it anyway? Farm level decision making in a semi arid India. Based on work done with Gadgil S, Narahari Rao. http://www.livingwithclimate.fi/linked/en/Rao.pdf

Stigter CJ (1993) Research on microclimate management and manipulation in multiple cropping: its contribution to agricultural production meteorology in tropical climates. Invited paper, National Seminar on Agricultural Production and Protection Meteorology, CASAM, Pune

Stigter CJ (2005) Climate-related extreme events: a review of adaptation options. Asian Climate Training Course, ADPC, Bangkok. http://www.adpc.net/ece/ACT_Man/ACT-3.5-Adaptations.pdf

Stigter K (2008) Agrometeorological services under a changing climate: old wine in new bags. WMO-Bull 57(2):114–117

Stigter CJ, Baldy CM (1993) Manipulation of the microclimate by intercropping: making the best of services rendered. In: Sinoquet H, Cruz P (eds) Ecophysiology of tropical intercropping. INRA, Paris/Guadeloupe, pp 29–44

Walker S, Stigter CJ, Ofori E, Kyei-Baffour N (2011) Intercropping and its implications for soil management. In: Hatfield JL, Sauer TJ (eds) Soil management: building a stable base for agriculture. American Society of Agronomy, in press

III.3.1.(d) More Efficient Use of Agricultural Inputs as Part of Adoption of Preparedness Strategies: Multiple Cropping

Kulasekaran Ramesh

Climate is a big risk factor impacting on the performance of crop production systems and their management for profitable returns. Stewart et al. (1989) presented an interesting picture of the difficulty of achieving sustainability of an agricultural system because of varying temperature and moisture regimes. As temperatures increase and amounts of rainfall decrease, the development of sustainable cropping systems becomes more difficult. Soil degradation processes such as organic matter decline and soil erosion are generally accelerated as temperatures increase.

Climatic events also largely determine the efficiency of external inputs in farming. Meinke et al. (2004) indicated that extreme climate events such as severe droughts, floods, or temperature shocks often strongly impede agricultural development. Multiple cropping is a strategy reducing crop failures due to climatic risks (e.g. Baldy and Stigter 1997). The organization of multiple cropping systems necessarily encompasses a wide range of decision-making steps, each of which has to be implemented at an optimum time for the efficient use of the applied inputs. The main strategic decisions for which climate information is needed are the identification of appropriate choices of crops, cropping systems and their organization, in tune with the prevailing climatic conditions. To cope with risks and uncertainties in agricultural production through improved preparedness of and with farmers and their communities through agrometeorological services, multiple cropping is a must.

Chikoore and Unganai (2001) listed from pilot studies that farmers require basic information about the following in order to make decisions on agricultural practices and this also applies to intercropping/multiple cropping situations:

- Onset date of the main rains
- Quality of the rainy season (rainfall amount)
- Cessation date of the main rains
- Temporal and spatial distribution of the main rains

K. Ramesh (✉)
IHBT(CSIR), Palampur, India; IISS(ICAR), Bhopal, India
e-mail: ramechek@yahoo.co.in

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_30,

- Timing and frequency of active and dry periods (wet and dry spells)
- Agronomic recommendations in terms of which crop varieties to grow and so on.

The strategic use of other climate information for preparedness will be in the selection of a suitable region for a crop and indeed the choice of crops itself. This would ensure further decisions for efficient use of agricultural inputs in multiple cropping systems such as pesticides, fungicides, herbicides and fertilizer inputs and such other inputs as necessary for successful crop production (see also Box III.3.4). The following are examples of attempts to study efficient use of monetary inputs in multiple cropping but effects can also be negative.

Box III.3.4

Applied agrometeorology for multiple cropping in "preparedness for efficient use of agricultural inputs" covers among others: (i) intercropping for micro-climate manipulation to aid in better crop space organization; (ii) pests and disease reduction, including counteracting measures; (iii) wind damage reduction by intercropping (e.g. Stigter et al. 2002) and (iv) surface modification for other protective and productive purposes. Baldy and Stigter (1997) in this context deal with (a) interception of rainfall by multiple cropping systems: interception of rain by vegetation and soil; utilization of water by each component of the cropping system; soil fertility aspects of rain; (b) other climatic factors: air and surface temperatures; profiles of wind and water vapour within vegetation; (c) solar radiation, carbon dioxide profiles and photosynthesis in multiple cropping; utilization of solar radiation and carbon dioxide by vegetation; variations in carbon dioxide contents and photosynthetic efficiency of each layer of a multiple cropping and (d) energy balance and evapotranspiration in multiple cropping: modifications of the energy balance due to vegetation; differences between canopy layers; application of evapotranspiration methods. In the epilogue of Baldy and Stigter (1997) they argue in the section "Multiple cropping and agrometeorology of limiting factors" that LEISA faming systems are consequences of adaptations of subsistence and near-subsistence farmers to changing limiting factors of their environment, that change so much in extent and character that the required input adaptations very often cannot keep pace with these multiple changes.

Diseases: Moreno (1977) speculated that the increased severity of "angular leaf spot" observed when beans were grown with maize was due to prolonged periods of high humidity under a maize canopy, because beans intercropped with sweet potatoes and/or cassava in his studies had lower severity than beans grown alone. The increased relative humidity and decreased leaf temperatures in maize intercrops would tend to favor leaf wetness duration and so the disease. Wind velocity was reduced by 55–63% in the intercrop in relation to the monocrop. Maize in an intercrop will reduce wind velocities substantially and the wind speed reduction may have effect on diseases, again via leaf wetness duration (Boudreau 2007).

Positive effects on coffee berry disease have been reported from opening up coffee plantations through pruning, lowering humidity in the coffee crop (Stigter et al. 1992). Intercropping with marigold induced a significant ($*P < 0.05$) reduction in tomato early blight caused by *Alternaria solani* by altering the microclimatic conditions in the canopy, particularly by reducing the number of hours per day with relative humidity $\geq$92%, thus diminishing conidial development (Rodriguez et al. 2003).

Insect pests: intercropping is also a strategy to reduce insect pests. Theunissen (1994) has discussed the intercropping of field vegetables with other species such as clovers that show insect pest suppression, which may make chemical control unnecessary. Insects may feed preferentially on the second crop, or it may provide a more favorable habitat to increase natural enemies (Strand 2000), minimizing the need for pesticidal input.

Weeds: intercropping minimizes weed menace through several means. Shading, higher humidity and lower temperatures under the intercrop canopies were most likely the mechanisms which caused the decline of "Striga" numbers in intercropping systems of peanut, bean and soybean in maize (Oswald et al. 2002) in western Kenya.

Nutrients: inclusion of "Azolla" in low land rice (dual cropping) increased rice yield (Singh 1989) while conjunctive use of "Azolla" with mineral N increased rice yield more than either of the two (Jayanthi et al. 1998). The rice plants created a conducive environment for "Azolla" growth. Ramesh (2002) could find higher growth of "Azolla" during the cool season compared to the hot season in India under a rice system. Ramesh and Chandrasekharan (2004) investigated the soil organic carbon build-up and its dynamics in rice – rice cropping system by including a green manure (*Sesbania rostrata* Berm.) as an intercrop at 4:1 ratio (additively) and found improvement in efficiency of applied nutrient inputs.

Green belts: Pryor and Nadler (2006) explained that structures that reduce the flow of wind over a field have many advantages such as soil erosion control and snow catching. The reduction in wind velocity due to a shelterbelt will also decrease the rate of crop evapotranspiration. While areas near shelterbelts have the potential of producing higher yields when moisture is limiting, they may also create regions of excess moisture. Particularly under irrigation that is applied uniformly over a field, areas that transpire less moisture will remain wetter than areas that require more water. Under non-irrigated conditions during a dry season, this would be favorable; however under conditions of excess moisture or heavy irrigation, these areas are most prone to the development and spread of diseases.

Field windbreaks have been planted primarily for soil erosion control, but they also affect the growth and yield of nearby crops by modifying the crop's microclimate (summer effects) or by trapping snow for soil water gain (winter effects).

Results showed that wheat yield increases adjacent to non-competitive barriers were due to increased winter soil moisture accretion resulting from snow catch (Frank and Willis 1978). A major effect of a windbreak may be to reduce the incidence of low frequency, high magnitude damage events such as sandblasting or lodging (e.g. Stigter et al. 2002). Shelter may improve water use efficiency in irrigated crops by increasing yields and reducing water use (Cleugh 1998).

In addition to the above, synergistic association between component crops was also achieved, possibly again due to microclimatic modification. Intercropping peppermint with soybean resulted in yield and quality increases in the essential oil, compared to sole peppermint cultivation (Maffei and Mucciarelli 2003).

This section is finalized by examples of the efficient use of non-monetary inputs.

Soil: on slopy and erosion prone land, erosion permitting (e.g. millets) and resisting (e.g. pulses) crops are raised in alternate rows so as to circumvent the erosivity of the precipitation and erodibility of the nutrient rich top soil. This system underpins the soil use as well as the applied input use efficiency maximization. Hedgerow intercropping was also successfully used that way by Kinama et al. (2007) who explain the importance of high flow resistance of a tilled soil surface and of what is on the surface or protruding from it. In this case, a negative role was played by competition between hedges and crops.

Space: in low temperature and frost prone areas, when the main crop becomes dormant, an additional crop is raised to fit the dormancy period so that the soil resources are conserved besides higher land utilization efficiency. An example of this kind of multiple cropping was discussed by Ramesh et al. (2007), where wheat is intercropped in *Stevia rebaudiana* (a zero calorie sweetener) in the western Himalayan region of India. When the plant spacings are altered in intercropping to utilize the space best and avoid inter-plant competition, energy balances, that is net radiation, soil heat flux, latent heat flux and sensible heat flux also vary.

Water: wherever precipitation is scarce, intercropping of oil seeds and pulses with pearl millet would ensure making the best use of soil and inter-row moisture harvesting. Intercropping *Acacia saligna* with sorghum and cowpea increased water use efficiency in an agroforestry trial (Droppelmann et al. 2000). Maize/bean intercropping in a semi-arid region of South Africa improved water use efficiency (Tsubo et al. 2003). In rainfed millet/cowpea and millet/sorghum/cowpea intercropping in northern Nigeria, an improvement of these cereal/legume intercropping systems in terms of microclimate improvement may involve a reduction in plant densities of the tillering and faster dry matter accumulating millet component, while the low growing and ground covering cowpea component density is increased. This may result in more efficient use of soil water while the intercropping systems radiation interception, soil water conservation, ground shading for weed suppression and reduced soil temperature fluctuations and soil evaporation are enhanced (e.g. Oluwasemire 2007).

References

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Boudreau MA (2007) Effect of intercropping beans with maize on the severity of angular leaf spot of beans in Kenya. Plant Pathol 42:16–25

Chikoore H, Unganai L (2001) Integrating climate forecast information in agricultural management: A perspective from Southern Africa. Presentation at the Open Meeting of the Global Environmental Change Research Community, Rio de Janeiro, 6–8 October, no pages given

Cleugh HA (1998) Effects of windbreaks on airflow, microclimates and crop yields. Agrofor Syst 41:55–84

Droppelmann K, Lehmann J, Ephrath J, Berliner, P (2000) Water use efficiency and uptake patterns in a runoff agroforestry system in an arid environment. Agrofor Syst 49:223–243

Frank B, Willis WO (1978) Effect of winter and summer windbreaks on soil water gain and spring wheat yield. Soil Sci Soc Am J 42:950–953 http://www.unl.edu/nac/brochures/ec1763/index.html

Jayanthi MU, Rajagopal V, Shantharam MV (1998) Studies on conjunctive use of *Azolla* and fertilizer nitrogen in rice cultivation. In: Kannaiyan S (ed) Cyanobacterial biofertilizers for rice crop. Tamil Nadu Agricultural University, Coimbatore, pp 204–208

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2007) Contour hedgerows and grass strips for erosion and runoff control in semi-arid Kenya. Arid Land Res Manag 21:1–19

Maffei M, Mucciarelli M (2003) Essential oil yield in peppermint/soybean strip intercropping. Field Crops Res 84:229–240

Meinke H, Donald L, DeVoil P, Power B, Baethgen W, Howden M, Allan R, Bates B (2004) How predictable is the climate and how can we use it in managing cropping risks? "New directions for a diverse planet". Proceedings of the 4th International Crop Science Congress, 26 September–1 October, Brisbane. Published on CD-ROM. See www.cropscience.org.au

Moreno RA (1977) Efecto de diferentes sistemas de cultivo sobre la severidad de la mancha angular del frijol *(Phaseolus vulgaris L)*, causada por *Isariopsis griseola* Sacc. Agron Costaric 1:39–42

Oluwasemire KO (2007) Third prize in the INSAM contest of 2006 of best examples of agrometeorological services. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology.

Oswald A, Ransom JK, Kroschel J, Sauerborn J (2002) Intercropping controls *Striga* in maize based farming systems. Crop Prot 21:367–374

Pryor D, Nadler A (2006) Examining micro-climate effects in field crop production. http://umanitoba. ca/afs/agronomists_conf/proceedings/2006/nadler_pryor_examining_micro_climate.pdf

Ramesh K (2002) Studies on intensive manuring in rice-rice cropping system in western zone of Tamil Nadu. Thesis submitted to Tamil Nadu Agricultural University, Coimbatore

Ramesh K, Chandrasekharan B (2004) Soil organic carbon build up and dynamics in rice-rice cropping systems. J Agron Crop Sci 190:21–27

Ramesh K, Singh V, Ahuja PS (2007) Production potential of *Stevia rebaudiana* under intercropping systems. Arch Agron Soil Sci 53:443–458

Rodriguez OG, Mejía EZ, Hernández VAG, Muñoz ML and Soriano EC (2003) Allelopathy and microclimatic modification of intercropping with marigold on tomato early blight disease development. Field Crops Res 83:27–34

Singh PK (1989) Use of Azolla in Asian agriculture. Appl Agric Res 4:149–161

Stewart BA, Lal R, El-Swaify SA (1989) Sustaining the resource base of an expanding world agriculture. Paper Presented at the Workshop on Mechanisms for a Productive and Sustainable Soil Resource Base,, Edmonton, 29–30 July, no pages given

Stigter CJ (coord & ed), Karing PH, Stigter CJ, Chen W, Wilken GC (1992) Application of microclimate management and manipulation techniques in low external input agriculture. CAgM Report 43, WMO/TD 499, Geneva, 192pp

Stigter CJ, Mohammed AE, Al-amin NKN, Onyewotu LOZ, Oteng'i SBB, Kainkwa RMR (2002) Agroforestry solutions to some African wind problems. J Wind Engn Ind Aerodyn 90: 1101–1114

Strand JF (2000) Some agrometeorological aspects of pest and disease management for the 21st century. Agric For Meteorol 103:73–82

Theunissen J (1994) Intercropping in field vegetable crops: pest management by agrosystem diversification-an overview. Pestic Sci 42:65–68

Tsubo M, Mukhala E, Ogindo HO, Walker S (2003) Productivity of maize-bean intercropping in a semi-arid region of South Africa. Water SA 29:381–388. http://www.wrc.org.za

III.3.1.(e) Selection of (Changes in) Livestock Management Patterns: Multiple Cropping

Kees Stigter

It is clear from much grazing literature and rangeland literature that grass species suitable for livestock may be found sole or in grass/grass and grass/legumes association pastures (e.g. Lebed et al. 2004) as well as in large numbers of silvopastoral agroforestry systems for grazing and browsing (e.g. Gutteridge and Shelton 1998–2004; WCA 2004). However, in a very different mode, for example in Niger, with early rains, a china beans or feed-grade groundnuts relay crop (in millet) can produce quality forage at the end of the long enough growing season (Kleschenko et al. 2004). As in monocropping (see Sect. III.2.1.(e)), degradation aspects may influence livestock and fodder management (DFID 2002), but depending on the type of associations often differ very much in character for multiple cropping, that has appreciably more components that support sustainability. In all systems the service role of the trees in providing shade and shelter must also be taken into account as this aspect is often undervalued in assessing the productivity of agroforestry systems (e.g. Gutteridge and Shelton 1998–2004).

Also here "monoherding" one type of animal (e.g. Babushkin and Lebed 2002; WCA 2004) and multiple species "herding" (e.g. Lebed et al. 2004; WCA 2004) can be distinguished. Simple silvopastoral systems from grasses and trees are found in tundras, steppes and other arid as well as humid rangelands (Lebed et al. 2004). Baldy and Stigter (1993, 1997) reported that for soil protection in Mediterranean regions, various intercroppings were created between perennials such as vines or other fruit trees and fodder plants that cover the ground. They also quote classical work that proved that cover crops and cover plants can be used as pasture for many years without harmful and sometimes beneficial consequences for rubber, oil palm and cocoa trees. Wind protection of plantains with fodder trees shows the variation in multiple cropping systems concerned. In even more complex agroforestry, silvopastoral systems are also common (Box III.3.5).

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_31,

Box III.3.5

In even more complex agroforestry, silvopastoral systems are also common. Some have various grasses or other fodder crops/trees, which when low and dense may be considered a kind of live mulches, exemplified by the three strata forage system (pasture, tree legumes, large trees) in Bali, Indonesia (Gutteridge and Shelton 1998–2004), and the date palm oases (Baldy and Stigter 1991, 1993, 1997; Stigter and Baldy 1989, 1991). Other silvopastoral systems have fruit and timber trees associated with food and fodder crops, contributing to soil and water conservation, and livestock (e.g. Reddy and Ramakrishna 2004), while homegardens and multipurpose trees play their own many roles, the latter within or out of associations (WCA 2004).

In line with the above, it follows from contributions to WCA (2004) that shade, wind protection, water erosion protection, food, fodder and timber/fuel wood are (individually and in combinations, with or without influences on pastures) the main uses of trees (scattered, in belts or live fences) in silvopastoral agroforestry. Sooner or later much agroforestry will become silvopastoral (e.g. Exconde and Castillo 2004) and under arid rainfed conditions the latter systems appear almost the only viable agroforestry (e.g. Benzarti and Ben Youssef 2004). Often with protective properties, agroforestry serves food self-sufficiency and feed self-sufficiency better than any monocropping (Jiru 2004), even when yields of crops associated to trees are lower (WCA 2004). Also in developed countries silvopastoral agroforestry is recommended these days (e.g. Klopfenstein et al. 2007).

References

Babushkin OL, Lebed LV (2002) Validation of information requirements on livestock and pasture production in arid and semi-arid regions. CAgM Report 86. WMO/TD 1134, Geneva, 76pp

Baldy C, Stigter CJ (1991) Modifications du microclimat dans des cultures multiples en regions tropicales [Microclimate modification in multiple cropping in tropical regions.] In: Wolf JN (ed.) Influence du climat sur la production des cultures tropicales (Influence of the climate on the production of tropical crops). IFS/CTA, Stockholm, Sweden, pp 185–208

Baldy C, Stigter CJ (1993) Agrométéorologie des cultures multiples en régions chaudes. [Agrometeorology of multiple cropping in warm regions.] Collection “Du Labo au Terrain”. [Series “From the Lab to the Field”.] INRA, Paris, France avec CTA, Ede, 246pp

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Benzarti J, Ben Youssef S (2004) Agroforestry in semi-arid regions for agricultural lands having 200 mm annual complementary irrigation. Book of Abstracts p 297. First World Congress of Agroforestry. conference.ifas.ufl.edu/wca/

DFID (2002) Soil fertility and nutrient management. ODI Keysheet -Resource Management No. 7. http://www.keysheets.org/green_7_soils.pdf

Exconde AB, Castillo JAA (2004) Silvopasture: a touch of Philippine experience. Book of Abstracts p 236. First World Congress of Agroforestry. conference.ifas.ufl.edu/wca/
Gutteridge R, Shelton M (1998–2004) Trees/livestock examples, Paper 37. In: Elevitch CR (ed) The overstory book. Cultivating connections with trees. 2nd edn. PAR, Holualoa. http://agroforestry.net/overstory/overstory37.html
Jiru D (2004) Contribution of agroforestry to food, feed and wood self-sufficiency and sustainability in rural livelihoods in Ethiopia. Book of Abstracts p 59. First World Congress of Agroforestry. conference.ifas.ufl.edu/wca/
Kleschenko A, Grom L, Ndiaye M, Stefanski R (2004) The impacts of agrometeorological applications for sustainable management of farming, forestry and livestock systems. CAgM Report 92. WMO/TD 1175, Geneva, 70pp
Klopfenstein NB, Rietveld WJ, Carman RC, Clason TR, Sharrow SH, Garrett G, Anderson BE (2007) Silvopasture: an agroforestry practice. The Overstory, Paper 190. PAR, Holualoa. Originally: Agroforestry Notes (USDA-NAC) 8(1997), USDA Forest Service, 4pp. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1005& context=agroforestnotes
Lebed LV, Gandega Y, Rijks D (2004) Impact of agrometeorological information on rangeland and pasture ecology and management. CAgM Report 96. WMO/TD 1229, Geneva, 24pp
Reddy NN, Ramakrishna YS (2004) Agri-horti-silvi models for sustainable development in semi arid tropical regions of India – A participative approach. Book of Abstracts p 329. First World Congress of Agroforestry. conference.ifas.ufl.edu/wca/
Stigter CJ, Baldy C (1989) Agrometeorology of multiple cropping systems: biomass management and the low external input farmer. Second ICTP/SAPAM Workshop on the Applicability of Environmental Physics and Meteorology in Africa, Addis Ababa University, ICTP/SAPAM, Ethiopia, 13pp
Stigter CJ, Baldy C (1991) Microclimate and protection of the tropical agricultural environment. In: Wolf JN (ed) Influence du climat sur la production des cultures tropicales (Influence of the climate on the production of tropical crops). IFS/CTA, Stockholm, pp 172–184
WCA (2004) First World Congress of Agroforestry. Book of Abstracts. Working together for sustainable land use systems. conference.ifas.ufl.edu/wca/

III.3.1.(f) The Development of Microclimate Modification Patterns: Multiple Cropping

Kees Stigter

This is about the strategic use of (micro)climate information in the adoption of microclimate modification techniques in multiple cropping (e.g. Baldy and Stigter 1997). Stigter and Darnhofer's (1989) definition as given in Sect. III.2.1.(f) applies. Reijntjes et al. (1992) mentioned multiple cropping systems in their book first under protecting crops in minimizing losses due to pests and diseases. They were among the first to recognize the use of trees, shrubs, grasses and herbs as intercrops in such systems and to review their advantages in resource sharing and resource protection, including microclimate as a resource (see also Box III.3.6).

Box III.3.6

In some alley cropping, an intercropping system with trees in alleys, shade of the trees is important against weeds and surface drying before their pruning, such as in the "Inga alley cropping design". This must therefore be seen as an agrometeorological service to the farmers concerned. A system was designed in which the conditions found in virgin tropical forests were mimicked: minimize weed growth – first by tree shading then by leaf mulches – and recycle nutrients, including phosphorus, by using thick leaved nitrogen fixing trees providing sufficient biomass under the local sub-humid to humid climate conditions, without too limiting competition. After this system worked well with maize crops in Costa Rica, Honduran slash and burn farmers further developed the alley cropping of *Inga edulis* with maize and beans and with pepper as well as vanilla (Stigter 2007, 2008; WMO 2010). See also Box III.3.10 of Sect. III.3.2.(iv). Moreover, the trees do provide a not unimportant amount of fuelwood (e.g. Walker et al. 2011).

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_32,

Stigter (1994) reviewed in three Tables the variety of management alternatives and manipulation actions in multiple cropping that is so much larger than in monocropping. This larger variety is due to the scale of the activities, the amount of labour available, the generally low to medium level of external inputs applied and the rather harsh conditions of the tropical environment in general from which protection is needed (Stigter 1994).

The agrometeorology of microclimate modification was most completely treated for the first time by Baldy and Stigter (1993, 1997) now more than a decade to 15 years ago. Intercrops including a cereal as well as agroforestry systems were most thoroughly dealt with. A Chapter on agrometeorological consequences of traditional cropping techniques reviewed much of the authors' work in Africa in the 1970s and the 1980s in scientifically understanding related traditional knowledge on microclimate management and manipulation (Baldy and Stigter 1993, 1997).

Alley cropping, forest farming, riparian buffers, silvopasture and windbreaks are the subjects of today's temperate agroforestry (AfTA 2007). In coping with disease risks, the disease triangle of host, disease and (favorable) environment gives environmental management through tillage/mulching/flooding and stand density and composition decisions a function (Krupinsky et al. 2002). The latter may include planting densities, crop rotations, companion plantings, trap and decoy cropping, sowing strategies and other biological measures (e.g. University of Sydney 2003). Changes in microenvironment are an important part of such management tools (e.g. Gillespie 1994; Smith et al. 1994).

As to integrated pest management (IPM), the effective environment of an organism has been characterized as weather (see also McFarland and Strand 1994), food, habitat (shelter, nests) and other organisms. Environmental management for biological control is concerned with the functional environment, i.e., the physical elements and biotic elements that directly or indirectly impact survival, migration, reproduction, feeding and the behaviors associated with these life processes (Legner 2000).

Pest populations can be controlled directly through cultural control methods that modify the habitat, including multiple cropping. In IPM this is combined with conservation (maintenance of natural enemy abundance and diversity) and enhancement (increased immigration, tenure time, longevity, fertility and efficiency) strategies that can be used to manipulate natural enemies in agro-ecosystems (Legner 2000).

References

AfTA (2007) Association for Temperate Agroforestry. http://www.aftaweb.org/index.php

Baldy C, Stigter CJ (1993) Agrométéorologie des cultures multiples en régions chaudes. [Agrometeorology of multiple cropping in warm regions.] Collection "Du Labo au Terrain". [Series "From the Lab to the Field".] INRA, Paris, France avec CTA, Ede, 246pp

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Gillespie TJ (1994) Pest and disease relationships, Chapter 19. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York, pp 203–209

Krupinsky JM, Bailey KL, McMullen MP, Gossen BD, Turkington TK (2002) Managing plant disease risk in diversified cropping systems. Agron J 94:198–209. http://agron.scijournals.org/cgi/content/full/94/2/198#SEC3

Legner E (2000) Management of the environment to favor pest control. http://www.faculty.ucr.edu/~legneref/biotact/bc-58.htm

McFarland MJ, Strand JF (1994). Weather-wise planning in farm management, Chapter 26. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 264–272

Reijntjes C, Haverkort B, Waters-Bayer W (1992) Farming for the future. An introduction to low-external-input and sustainable agriculture. Macmillan/ILEIA, London/Leusden, 250pp

Smith DH, Smith WH, Reifsnyder WE (1994) Silviculture, pests and disease, forest and wildland fires, Chapter 20. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 210–219

Stigter CJ (1994) Management and manipulation of microclimate, Chapter 27. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 273–284

Stigter K (2007) *Inga* alley cropping as an agrometeorological service to slash and burn farmers. Available at the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology". Also used as Appendix I in Stigter (2008b).

Stigter K (2008) Coping with climate risks in agriculture needs farmer oriented research and extension policies (based on participation, preparedness and resilience). Paper Presented at the 1st Venezuelan Agrometeorology Congress, San Cristobal, Venezuela, November 2007. Scientia Agricola (Piracicaba, Brazil), 65 (special issue), pp 108–115. http://www.scielo.br/pdf/sa/v65nspe/a16v65nsp.pdf

Stigter CJ, Darnhofer T (1989) Quantification of microclimate near the soil surface, Appendix F. In: Anderson JM and Ingram JSI (eds) Tropical soil biology and fertility: a handbook of methods. IUBS/UNESCO, (MAB), C.A.B. International, Wallingford, pp 144–157

University of Sydney (2003) Plant pathology. Disease management: cultural management practices. http://bugs.bio.usyd.edu.au/PlantPathology/disease_mgmt/cultural_mgmt.html

Walker S, Stigter CJ, Ofori E, Kyei-Baffour N (2011) Intercropping and its implications for soil management. In: Hatfield JL, Sauer TJ (eds) Soil management: building a stable base for agriculture. American Society of Agronomy, in press

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by Stigter CJ. WMO, Geneva, in press

III.3.1.(g) Designs of (Changes in) Protection Measures Against Extreme Climate: Multiple Cropping

Kees Stigter

Adjust cropping systems, develop multiple cropping and raise multiple cropping indexes are explicitly mentioned by China's National Climate Change Programme (2007). In the USA, multiple cropping is considered to provide an insurance against the loss of a crop to freezes, hailstorms, and other crises in horticulture (Bachmann 2005). In some parts of the tropics, traditional technologies, such as multiple cropping and terracing, act to buffer the system against climate variability, conserve soil fertility, and increase yields (Rosenzweig and Liverman 1992).

In Lesotho, the expansion of mixed and multiple cropping systems featuring a diversified genetic base is a key feature for sustainability. The extension service should encourage changes in smallholder management practices which require little or no additional cash resources and which minimize risk (Chakela 1999). Bangladesh is for example already suffering from major extreme events and is relatively well equipped institutionally to face an increase in the incidence of extreme events. The country has a long experience in disaster management and is in a continuous process to improve on its capacity to mitigate the impacts of disasters as cyclones and floods. The Coastal Greenbelt Project is an example and key adaptations in agriculture would aim at changing agricultural practices to improving water efficiency and crop diversification (Koudstaal et al. 1999).

Farmers have traditionally dealt with risk by spreading their resources. They have always taken steps to build-in their own insurance through their cropping and planting strategies, careful that one failure will not prove to be a catastrophe. It is an approach that can be developed and enhanced by better forecasting and co-operative action with support for alternative crops and planting schedules (Cooperative programme on water and climate 2007). Beautiful examples under extreme drought conditions are water harvesting and planting methods reported from some areas of the Sudan, many of which are diversification and multiple cropping oriented. Changes have to do with policy measures and options and opportunities related to

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_33,

economical and other services (extension!) as well as equity. They also give insight in the causes and dangers of the Darfur conflicts (Osman-Elasha et al. 2006).

In these Sudanese case studies, community development projects contribute to reductions in the vulnerability of the people to climate hazards and other stresses. They strengthened livelihoods while taking into account frequent drought as one of the major threats to people in the region. These projects emphasized a holistic approach to increasing the natural, physical, financial, human and social capacities necessary for adaptive responses that are effective in reducing vulnerability. Some measures were motivated explicitly by the desire to reduce climate risks (e.g. water harvesting), some to expand livelihood options (e.g. introduction of new crops and types of livestock) (Osman-Elasha et al. 2006).

Important to the development of adaptive capacity is the timely dissemination of information on climate related hazards and vulnerabilities, and on the different practical types of adaptation measures and coping mechanisms that different stakeholders could implement in order to reduce the potential adverse impacts. Special consideration should be given to the integration of indigenous knowledge with regard to historical experience with climate variability and the traditional responses evolved over time. For example, the water harvesting techniques adopted in the Darfur area that have proved to contribute greatly to increasing community resilience to harsh drought conditions could be diffused more widely to adapt to future climate change (Oman-Elasha et al. 2006).

Implications in the above are confirmed by for example Stigter et al. (2005), NEF (2006), Kelly and Khinmaung (2007), Rathore and Stigter (2007) and Stigter (2008). In the agrometeorological services described in detail in Part II there are ample examples of designs of (changes in) protection measures against extreme climate in which multiple cropping is involved. We can mention INSAM protocols II.4 (Kenya), II.5 (Nigeria), II.9 (Kenya), II.12 (Sudan), II.14 (Nigeria), II.15 (Kenya), II.17 (India), II.18 (Tanzania) and CMA/CAU/APMP Agrometeorological Services Case Study II.C.VI (China). Of these nine case studies, seven have an agroforestry component.

References

Bachmann J (2005) Season extension techniques for market gardeners. National Sustainable Agriculture Information Service. http://attra.ncat.org/attra-pub/seasonext.html

Chakela QK (1999) State of the environment in Lesotho in 1997. National Environment Secretariat, Ministry of Environment, Gender and Youth Affairs. http://www.lesotho.gov.ls/documents/reports/report-environ-1997.htm

China's National Climate Change Programme (2007) National climate change programme. http://www.china.org.cn/english/environment/213624.htm

Cooperative programme on water and climate (2007) Coping options. www.waterandclimate.org/index.php?id=copingoptions896

Kelly C, Khinmaung J (2007) Prepare to live. Strengthening the resilience of communities to manage food security in the Sahel region. Tearfund. http://www.tearfund.org/webdocs/Website/campaigning/policy%20and%20research/Prepare%20to%20Live%20summary.pdf

Koudstaal R, Werners SE, Ahmed AU (1999) Considering adaptation to climate change towards a sustainable development of Bangladesh. http://www.mungo.nl/CC_Bangla.htm

NEF (2006) Up in smoke? Latin America and the Caribbean: the threat from climate change to the environment and human development. New Economics Foundation. http://www.neweconomics.org/gen/uploads/15erpvfzxbbipu552pnoo1f128082006213002.pdf

Osman-Elasha B, Goutbi N, Spanger-Siegfried E, Dougherty B, Hanafi A, Zakieldeen S, Sanjak A, Atti HA, Elhassan HM (2006) Adaptation strategies to increase human resilience against climate variability and change: lessons from the arid regions of Sudan. AIACC Working Paper No. 42, Washington. http://www.aiaccproject.org/working_papers/Working%20Papers/AIACC_WP42_Osman.pdf

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties in Asian regions. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 53–69

Rosenzweig C, Liverman D (1992) Predicted effects of climate change on agriculture: a comparison of temperate and tropical regions. http://www.ciesin.org/docs/004-145/004-145.html

Stigter K (2008) Coping with climate risks in agriculture needs farmer oriented research and extension policies (based on participation, preparedness and resilience). Paper Presented at the 1st Venezuelan Agrometeorology Congress, San Cristobal, November 2007. Scientia Agricola (Piracicaba, Brazil), 65(special issue), pp 108–115. http://www.scielo.br/pdf/sa/v65nspe/a16v65nsp.pdf

Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005) Using traditional methods and indigenous technologies for coping with climate variability. Clim Change 70:255–271

III.3.2 Coping with Climate Variability and Climate Change

III.3.2.(i) Improving the Issuing, Absorption and Use of Climate Forecast Information in Agricultural Production: Multiple Cropping

Kees Stigter and Ajit Govind

Current rates of climate change may cause unpredictable consequences in the future (IPCC 2007). This unpredictability could severely threaten agricultural productivity and socio-economic equilibrium in many areas of the world where the direct use of natural resources is critical for sustaining the livelihoods of its stakeholders (Salinger et al. 2000). Ideally, agrometeorological advisories, including climate forecasts, should focus on coping mechanisms or contingency measures that protect farmers from present or future climate (Lin 2007). Starting Sect. III.2.5.(ε) it was stated that improving coping strategies with weather and climate risks in monocropping very often demands the use of the science of agrometeorology in reducing limitations of production factors (e.g. Fischer et al. 2002; Stigter 2006; Sivakumar and Motha 2007; Stern 2007).

As to multiple cropping, among others Stigter and Baldy (1993) and Baldy and Stigter (1997) showed that the same is true for the agrometeorology of such more complex cropping systems, but that there is much more of traditional expert knowledge to start from in the less industrialized farming systems concerned, demanding attention for traditional/indigenous knowledge systems and experience (e.g. Baldy and Stigter 1997; Marsh 2001; Uran et al. 2001; Stigter et al. 2005; Van‘t Hooft 2007). This applies to forecasting issues as well.

There is now a better understanding by the scientific community of the climate, that is the natural and anthropogenic factors that have caused climate variability and change over the past century (Salinger 1994; Salinger et al. 1997, 1999). Although judicious management and plans can reduce uncertainties to some degree, annual weather variations, both within the growing season and in terms of extremes, are the main cause of crop yield variation. This is because climate change and its variability results in uncertainties, leading to significant crop and resource losses (Thomas et al. 2007) owing to constraints in scarce-resources (hydro-thermal conditions) or due to increased outbreaks of pest and diseases.

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageninge UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_34,

For multiple cropping, higher dependence of agriculture on climatic factors is the primary reason for its vulnerability and low adaptive-capacity among farmers in the developing world (World Bank 2000; Stigter 2006). On the other hand, the climatological hazards related to climate change can be mitigated with the agrometeorology of multiple cropping. It is here that also the forecasting aspects are different. Evidence of this can be found in other sections of this Chap. III.3 and in Stigter et al. (2005) and Stigter (2008). This evidence can be understood from the work by Baldy and Stigter (1997) and its abundant references and more recently from Walker et al. (2011) and some of the more recent references there.

An example was recently also given by Stigter et al. (2008a). This is on demonstration and extension of relay intercropping of late rice into lotus, enhanced by climate change, in Jiangxi Province, southern China. In the area concerned, a double rice crop (early rice and late rice) used to be grown everywhere and is still abundantly grown. Because of the slow global warming, the seasons become longer and are forecasted to change into that same direction. Now into lotus, that is sown by the end of March, early April, and gradually harvested between July and September, in some land late rice is transplanted as a relay crop, roughly between 10 and 20 August. This farming system change is advocated by extension.

Because of the lotus, the rice is 45 days in the nursery, 10 days longer than normal, so the rice is transplanted later than usual. But the land is now occupied after the lotus, that is harvested till September, while the later sown early maturing rice variety occupies the land till into November. The lotus normally fetches a high prize and the rice is an additional bonus. The lotus may lose 10% of its harvest because of the rice but under land scarcity the late rice is a useful addition. In the seventies this would not have been possible, but climate change makes it possible. Of course under early cold waves the rice will lose in production. For more details see CMA/CAU/APMP Agrometeorological Services case study Sect. II.C.VI.

An important lesson learned here is the economically successful adaptation that is provided to the forecast of a changing climate (see also Bakheit et al. 2001, in a completely different context). Only some decades ago, the present development would not have been feasible in this farming system. This is a warning for any scenarios projecting present cropping systems into the future and forecasting their suffering from climate change. There are many ways for adaptation through agrometeorological services and farmers are keen to innovate and follow up (e.g. again Bakheit et al. 2001, but also Winarto et al. 2008).

Another example from China are the mixed reactions to experiencing and forecasting of global warming in the North China Plain reported by Stigter et al. (2005). Originally a change from double cropping to more traditional intercropping of early maize with late wheat took place. In southern parts intercropping, that gave higher degree days for maize, was after a decade again replaced by double cropping, while in cooler mountainous areas and further North the intercropping was kept.

Where this subject was dealt with for monocropping (in this Section), it was suggested that in an agrarian economy, an ideal way to cope with climate change/climate variability is to develop strategies/plans that are implemented at multiple spatial (national, provincial, county/district or at grass-root/farm scales) and temporal (annual, seasonal or daily) scales. This ensemble of strategies in the form of agro-meteorological advices/services should indeed be implemented simultaneously to get the maximum benefit to the local farmer or the economy and this is even more complex for multiple cropping systems for which only few examples exist in which issuing, absorption and use of climate forecasts are reported on.

From a research carried out in Southern Africa, a region facing multiple stress factors on agricultural production, Vogel and O'brien (2006) concluded that the potential role of climate forecast information in reducing food insecurity are quite promising. This is because it facilitates the better understanding of the physical aspects of climate by the "end-users" who use such forecasts. In a complex socio-economic situation, climate forecast information delivered in the conventional manner is not efficient. Their study indicates that alternative modes augmenting the existing means of information delivery are necessary to sustainably cope with climate risks in the region.

For extension in the Chinese case study of an agrometeorological service in Jiangxi discussed above, of the relay intercropping of late rice with lotus, eight times a kind of Climate Field Classes was organized to demonstrate and popularize the method with the target groups concerned and an office was available for training (Stigter et al. 2008a). As we earlier indicated, a comparison of such an approach (e.g. Winarto et al. 2008) with the "cascade" down coming of extension information in China (Stigter et al. 2008b) would be a great last phase of the pilot projects started there.

Information dissemination in Hebei of the service of the forecasting of days with less than 3 h of sunshine and some weather disasters, including low temperatures, for vegetable crops (in monoculture or intercropping) in winter in plastic greenhouses is to the government and the farmers through weather forecasts (Stigter et al. 2008c). So, finally there is the lesson here of the importance of simply using existing and improved general – and of course where possible special – weather forecasts and short range climate forecasts explicitly for providing the required information as an agrometeorological service.

This is very much in line with Murthy's pleas from his work at ANGRAU in Hyderabad (Murthy 2008; WMO 2010), where published newspaper weather forecasts are used with farmers (see also Box III.3.23 in Sect. III.3.5.(δ)). In several places in China, apart from radio and TV as well as SMS messages on mobile phones (see Box III.3.7), this can also be done through telephone information that can be obtained at special numbers, through printed leaflets of some of the information and via the internet with separate weather and agricultural sites (Stigter et al. 2008c).

Box III.3.7

In China indeed multiple channels are used to for example make forecasts or other information for decision making known. The sowing advices in Bayabnaoemeng, Inner Mongolia are based on a simple long term climate forecasting model. They are spread by reports to the government, connections with other departments (Agronomy, Engineering/Machinery etc.) and field meetings at various levels, that include extension officers and farmers in the same cascade system described already in Sect. III.2.2.(i). If serious adaptations are necessary, a television/radio/SMS system is used, because such urgent response farming broadcasting of sowing advices is via television programmes (received here mostly by cable), rural radio, rural community radio, and SMS messages, that are becoming more and more popular there. This latter channel of urgent information flow appears to work well because the reception of such (short) messages is related to the small payment made for the mobile telephones by each farmer in the months in which this is important (Stigter et al. 2008b).

In Xinfeng, Guanzhou County, Jiangxi Province, communication channels of forecasts and warnings related to the commercial growth of navel oranges were also discussed (Stigter et al. 2008a). Fruit Departments are intermediaries and have lists of farmers with their contacting information. They transform the weather information and messages into absorbable forms. Every township has extension/technician people, every village has farmer technicians. The second information channel are "Societies" for different crops such as the oranges, which are loosely organized "interest groups". The third information channel are the "Cooperatives" of farmers, that are official, legal structures, like companies, that can also sign official papers. An impressive training centre we here also visited.

References

Bakheit NI, Stigter K, Abdalla AT (2001) Underground storage of sorghum as a banking alternative. Low Ext Input Sust Agric (LEISA) Mag 17(1):13

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Fischer G, Shah M, van Velthuizen H (2002) Climate change and agricultural vulnerability. IIASA report for the World Summit on Sustainable Development, Johannesburg. IIASA Publications Department, Vienna, Austria. http://www.iiasa.ac.at/Research/LUC/JB-Report.pdf

IPCC (2007) Climate change 2007: the physical science base. Summary for policy makers. http://www.ipcc.ch/SPM2feb07.pdf

Lin BB (2007) Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. Agric For Meteorol 144:85–94

Marsh N (2001) It's time to celebrate the spirit of the African farmer. Low Ext Input Sust Agric (LEISA) Mag 17(1):14

Murthy VRK (2008) Report on the project entitled "WMO-ANGRAU-DST sponsored Roving Seminars on Weather, Climate and Farmers". Available at the INSAM website (www.agrometeorology.org) under "Needs for agrometeorological solutions to farming problems" of 19 February

Salinger MJ (1994) Climate variability, agriculture and forests. Technical Note 196, WMO 802, Geneva, 152pp

Salinger MJ, Desjardins R, Jones MB, Sivakumar MVK, Strommen ND, Veerasamy S, Wu Lianhai (1997) Climate variability, agriculture and forestry: an update. Technical Note 199, WMO 841, Geneva, 51pp

Salinger MJ, Desjardins RL, Janzen H, Karing PH, Veeresamy S, Zipoli G (1999) Climate variability, agriculture and forestry: towards sustainability. Report of the CAgM-XI Rapporteurs on the Effects of Climate Variability and Climate Change on Agriculture and Forestry, WMO, Geneva, 97pp

Salinger MJ, Stigter CJ, Das HP (2000) Agrometeorological adaptation strategies to increasing climate variability and climate change. Agric For Meteorol 103:167–184

Sivakumar MVK, Motha R (eds) (2007) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, 503pp

Stern N (2007) The economics of climate change. Cambridge University Press, Cambridge, 692pp

Stigter K (2006) Scientific research in Africa in the 21st century, in need of a change of approach. Afr J Agric Res 1:4–8

Stigter K (2008) Cocoa and climate change. Can the lame help the blind? Updated Version of an Invited Paper Presented at the "2008 Indonesian Cocoa Symposium", Sanur, 28–30 October. Available on the INSAM web site (www.agrometeorology.org) under "Needs for agrometeorological solutions to farming problems" of 3 November

Stigter CJ, Baldy CM (1993) Manipulation of the microclimate by intercropping: making the best of services rendered. In: Sinoquet H, Cruz P (eds) Ecophysiology of tropical intercropping, INRA, Paris/Guadeloupe pp 29–44

Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005) Using traditional methods and indigenous technologies for coping with climate variability. Clim Change 70:255–271

Stigter K, Xie Yuanyu, Liao Zhihui, Rao Qiusheng, Li Yingchun, Zheng Dawei, Wang Shili, Ma Yuping (2008a) Recent identification of two agrometeorological services in Jiangxi Province, Southern China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

Stigter K, Niu Baoliang, Yang Song, Hou Qiong, Zheng Dawei, Ma Yuping, Wang Shili (2008b) Recent identification of two agrometeorological services in Inner Mongolia Autonomous Region, Northern China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

Stigter K, Li Chunqiang, Zheng Dawei, Wang Shili, Ma Yuping (2008c) Further identification of two agrometeorological services in Hebei Province, China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

Thomas DSG, Twyman C, Osbahr H, Hewitson B (2007) Adaptation to climate change and variability: farmer responses to intra-seasonal precipitation trends in South Africa. Clim Change 83:301–322

Uran G, Hartono D, Thijssen R (2001) Far from all oil palm turmoil. Low Ext Input Sust Agric (LEISA) Mag 17(1):16–17

Van 't Hooft K (2007) Endogenous development in practice. ETC Compas, Leusden, 87pp

Vogel C, O'brien K (2006) Who can eat information? Examining the effectiveness of seasonal climate forecasts and regional climate risk management strategies. Clim Res 33:111–122

Walker S, Stigter CJ, Ofori E, Kyei-Baffour N (2011) Intercropping and its implications for soil management. In: Hatfield JL, Sauer TJ (eds) Soil management: building a stable base for agriculture. American Society of Agronomy, in press

Winarto YT, Stigter K, Anantasari E, Hidayah SN (2008) Climate Field Schools in Indonesia: coping with climate change and beyond. Low Ext Input Sust Agric (LEISA) Mag 24(4):16–18

World Bank (2000) Can Africa claim the 21st century? World Bank, Washington DC, 278pp. http://siteresources.worldbank.org/INTAFRICA/Resources/complete.pdf

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by C.J. Stigter. WMO, Geneva, in press

III.3.2.(ii) The Sustainable Development and Use of Agro-Ecosystems: Multiple Cropping

Sue Walker, Emmanuel Ofori, Nicholas Kyei-Baffour, and Kees Stigter

Agro-ecosystems are ecosystems managed by farmers. Ajit Govind (pers comm 2008) indicates that adoption of farming systems approaches that integrate ecological, economical and social aspects of an agro-ecosystem, have increased over recent decades. These farming systems are often tailored towards improving the short- and long-term prospects for sustainability, and are implemented by farmers themselves in conjunction with research and extension organizations (Gibon et al. 1999; Kropff et al. 2001; Gibon 2005). This type of an integrated approach has the potential to comprehensively manage the scarce natural resources in many of the vulnerable agro-ecosystems of the world that are especially prone to the adverse effects of climate change and anthropogenic land degradation. The habitat change that climate change will cause (Box III.3.8) also demands such an approach.

Box III.3.8

Not yet mentioned in Sect. III.2.2.(ii), although implicated and of importance to the further application of multiple cropping, is the fact that a number of recent studies have estimated the likely changes in land suitability, potential yields, and agricultural production on the current suite of crops and cultivars available today. Climate change will result in regional shifts in suitable cropland in the mid latitudes, arid to semi-arid tropics and sub-tropical regions. In sub-Saharan Africa alone, land for double cropping could decline by between 10 and 20 million hectares, and land suitable for triple cropping could decline by 5 million to 10 million ha (Schmidhuber and Tubiello 2007). At the regional level (Fischer et al. 2002) similar approaches indicate that under climate change, the biggest losses in suitable cropland are likely to be

S. Walker (✉)
Department of Soil, Crop and Climate Sciences, University of the Free State, Bloemfontein, South Africa
e-mail: walkers.sci@ufs.ac.za

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_35,

in Africa, whereas the largest expansion of suitable cropland may be expected in the Russian Federation and Central Asia.

Increasing climate variability also affects agriculture in that for any agricultural commodity, increasing variation in yield between years will be related to increasingly variable growing season weather. No studies have been reported on how this affects multiple cropping results. The same applies to the increasingly variable weather influencing insects, disease, and weeds, which in turn affect agricultural production. Most recognizable effects that in general will start to vary more or worsen are:

a. Disease pressure on crops and domestic animals will likely increase and will allow proliferation and higher survival rates of pathogens and parasites.
b. Regional warming and changes in rainfall, that will also affect spatial and temporal distribution of pests and diseases.
c. Changes in the lengths of growing seasons (already noted, e.g. Boer 2007; Winarto et al. 2008 for Indonesia).
d. Influences on forest productivity, species composition, and the frequency and magnitude of disturbances (forest fires, insect outbreaks, severe droughts, and landslides resulting from intense storms that impact forests). There is much more in sub-chapter III.4.
e. Water quantity and water quality (variations in the storage, fluxes, and quality of water, all of which are sensitive to climate change). Stream temperatures are likely to increase as the climate warms, and are very likely to have both direct and indirect effects on aquatic ecosystems. Changes in temperature will be most evident during low flow periods, when they are of greatest concern.
f. Biodiversity (including changes in growing season, phenology, primary production, and species distributions and species diversity).

While in the long run food production may not be threatened globally, those least able to cope will likely bear additional adverse impacts (WRI 2005). The estimate for Africa is that 25–40% of species habitats could be lost, affecting both food and non-food crops. Habitat change is already underway in some areas, leading to species range shifts and changes in plant diversity which include indigenous foods and plant-based medicines (McClean et al. 2005).

For example, intercropping components adopted by farmers in the Nigerian Sudan savanna on sandy soils are grown in low densities, to minimize risks and exploit resources in a good cropping season (Bationo and Ntare 2000; Oluwasemire et al. 2002). An *Acacia senegal* agroforestry system that has been traditionally practised in the Sudano-Sahelian region is complex and yet a dynamically resilient system across a wide range of climates, soils and topography (Raddad and Luukkanen 2007). In North America multiple cropping is practiced usually in the form of relay cropping wheat and soybeans. The relay technique enables the production of a second crop in areas where time for a second crop following the wheat harvest is inadequate (Beuerlein 2001).

Walker et al. (2011), in their introduction, state that intercropping has always been part of the traditional farming systems in the tropics. The local knowledge about the most appropriate mixes of crops has been passed from generation to generation. When people look at the natural ecosystems, they see many species growing together in each location, so it was natural to also plant in agro-ecosystems more than one crop species in the field at one time or during one season. These polyculture cropping systems that have been traditionally used by people in developing countries in Africa, Asia and Latin America can provide a key solution to sustainable agriculture in the tropics (Francis and Adipala 1994; Rusinamhodzi et al. 2006).

Scientific research has been carried out on a range of intercropping systems (Baldy and Stigter 1997). Connolly et al. (2001) report on studies in at least 50 countries and with various combinations of a total of 55 different species. The top four species in these studies were maize, cowpea, wheat and groundnut and two out of three of the studies were carried out on-station, while half of the studies only lasted 1 year (Connolly et al. 2001). In addition to providing sustainable cropping systems (Connolly et al. 2001), the intercropping of a cereal together with a legume enhances food production. In areas of Africa, the legume intercropped with maize has provided a stabilizing effect on the food security of the small holder farmers (Snapp et al. 1998). The intercropping systems provide the best alternative for the semi-arid areas by providing a more stable production, that is less variable under the variable climate (Rose and Adiku 2001).

The practice of multiple cropping takes into account the climate, adequate water to produce two or more crops, suitable soil type, environmental constraints, farmer's objectives, location and available technology. In the humid tropics, cassava is often intercropped with maize, cowpea, melon, groundnut, okra, though there are other mixtures such as maize/cassava/melon, maize/cassava/okra/melon, maize/cassava/okra/cowpea, maize/yam/cowpea and maize/yam/groundnuts (e.g. Baldy and Stigter 1997).

In (somewhat) drier areas, common intercropping systems include maize, millet and sorghum as dominant cereal crops, intercropped with legume crops such as beans, cowpea, groundnut, pigeon pea and soybean as the companion plant species. Stern (1984) reported that about 80% of cultivated land in West Africa was under intercropping. The major cereals adapted to the rainfed region of the Nigerian Sudan savanna are pearl millet and sorghum. These cereals are predominantly intercropped with cowpea and/or groundnut, in various mixtures (Oluwasemire et al. 2002). Maize/cowpea is promoted among small-holder farms in Zimbabwe (Ncube et al. 2007), maize/pigeon pea is practiced in Malawi (Gladwin et al. 2001), and northern Mozambique. According to Olufajo (1992), in the traditional soybean growing areas of Nigeria, soybean is commonly intercropped with cereals like maize, sorghum and millet. According to Ofori and Stern (1987), cereal and legume intercropping is recognized as common agro-ecosystems throughout tropical developing countries for both capital intensive commercial and subsistence farming.

In South Africa, Tsubo et al. (2003) presented a study on the yield and growth advantages of maize/bean intercropping which is representative of other African regions. From the study, it was concluded that when farmers plant maize associated with beans, it is more advantageous than sole cropping and that maize/bean intercrops can be recommended for small scale farmers in the region. By using the Land Equivalent Ratio (LER) one is able to compare the production of the intercrop and express it relative to the yield from a sole crop of the dominant species (e.g. Beets 1982; Baldy and Stigter 1997). Walker et al. (2011) report that overall, the intercropping maize/bean system was more effective and more efficient relative to the sole plantings, as all the sowing dates gave LER higher than 1.0 (Tsubo et al. 2004). In general, in these trials the maize yield was not decreased by the addition of beans as an intercrop, showing the advantage of this intercropping system (Tsubo et al. 2005). The high production of the intercrop can be simply explained by the more efficient use of the limited natural resources, namely radiation and water (e.g. Walker et al. 2011).

When considering the radiation penetration into the maize canopy, some of the solar radiation will usually be transmitted to the soil surface. However, with a bean intercrop, this radiation will be intercepted by the bean crop. This provides more efficient radiation capture by the intercrop than sole cropping systems (e.g. Rose and Adiku 2001). Walker et al. (2011) conclude that from many studies across Africa, it seems that the intercropping systems have a higher productivity than the sole cereal systems in semi-arid areas – for example: maize/legume (e.g. Pilbeam et al. 1994; Alemseged et al. 1996a, b) and sorghum/legumes (Rees 1986; Lightfoot and Tayler 1987). These yield advantages have also been explained by the more efficient use of both the radiation and the water. Therefore, the C4-cereal/legume intercropping can be recommended for the semi-arid areas of Africa as they produce more stable and reliable crops despite climate variability, a sign of sustainability (Walker et al. 2011).

More than half of the studies carried out on intercropping focus on the factors effecting intercropping productivity and the economic benefit of using more than one crop on a single field in any season (Connolly et al. 2001). A range of treatments concerned with various management manipulations (fertilizer, spacing, weeding, irrigation, time of planting etc.) and their effect on production have been investigated (Connolly et al. 2001).

However, there seems to be little interest in investigating the mechanisms or processes that result in the changes (e.g. Stigter and Baldy 1993; Carrubba et al. 2008) and many studies fail to measure any of the soil effects. Walker et al. (2011) conclude that it is a pity that not more soil information is available from the many intercropping studies that have been carried out in Africa. From information shown by them it may be seen that intercropping holds a variety of advantages to sustain the soil as a natural resource. The effects of the residual legume roots in the soil will have a longer term effect on the soil fertility and cannot be removed for other uses in the farming system. In contrast, the N rich above ground biomass from the legumes is most often removed and so does not remain as a benefit to the soil resource base (Walker et al. 2011).

References

Alemseged YB, King GW, Coppock LR, Tothill JC (1996a) A preliminary investigation of the potential for maize-legume intercropping in thee semi-arid area of Sidamo region, Ethiopia. I. Maize response. S Afr J Plant Soil 13:120–124

Alemseged YB, King GW, Coppock LR, Tothill JC (1996b) A preliminary investigation of the potential for maize-legume intercropping in the semi-arid area of Sidamo region, Ethiopia. II. Legume response. S Afr J Plant Soil 13:125–130

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Bationo A, Ntare BR (2000) Rotation and nitrogen fertilizer effects on millet, cowpea and groundnut yield and chemical properties in a sandy soil in the semi-arid tropics, west Africa. J Agric Sci 134:277–284

Beets WC (1982) Multiple cropping and tropical farming systems. Westview Press, Boulders, 156pp

Beuerlein J (2001) Relay cropping wheat and soyabeans. Ohio State University Extension Fact Sheet, Horticulture and Crop Science AGF – 106 – 01:1–5

Boer R (2007) Is our agriculture system resilient to climate change? The Jakarta Post, 4 December, p 9

Carrubba A, la Torre RL, Saiano F, Aiello P (2008) Sustainable production of fennel and hill by intercropping. Agron Sustain Dev 28:247–256

Connolly J, Goma HC, Rahim K (2001) The information content of indicators in intercropping research. Agric Ecosyst Environ 87:191–207

Fischer G, Shah M, van Velthuizen H (2002) Climate change and agricultural vulnerability. IIASA report for the World Summit on Sustainable Development, Johannesburg. IIASA Publications Department, Vienna, Austria. http://www.iiasa.ac.at/Research/LUC/JB-Report.pdf

Francis AC, Adipala E (1994) Tropical intercropping systems. What is the future? Afr Crop Sci J 2:131–133

Gibon A (2005) Managing grassland for production, the environment and the landscape. Challenges at the farm and the landscape level. Livest Prod Sci 96:11–31

Gibon A, Sibbald AR, Flamant JC, Lhoste P, Revilla R, Rubino R, Sorensen JT (1999) Livestock farming systems research in Europe and its potential contribution for managing towards sustainability in livestock farming. Livest Prod Sci 61:121–137

Gladwin CH, Thomson AM, Peterson JS, Anderson AS (2001) Addressing food security in Africa via a multiple livelihood strategies of women farmers. Food Pol 26:177–207

Kropff MJ, Bouma J, Jones JW (2001) Systems approaches for the design of sustainable agro-ecosystems. Agric Syst 70:369–393

Lightfoot CWF, Tayler RS (1987) Intercropping sorghum with cowpea in dryland farming systems in Botswana. I. Field experiments and relative advantages of intercropping. Exp Agric 23: 425–434

McClean CJ, Lovett JC, Kuper W, Hannah L, Sommer JH, Barthlott W, Termansen M, Smith GF, Tokumine S, Taplin JRD (2005) African plant diversity and climate change. Ann Missouri Bot Gard 92(2):139–152

Ncube B, Twomlow SJ, van Wijk MT, Dimes JP, Giller KE (2007) Productivity and residual benefits of grain legumes to sorghum under semi-arid conditions in south western Zimbabwe. Plant Soil 299:1–15

Ofori F, Stern WR (1987) Cereal-legume intercropping systems. Adv Agron 41:41–90

Olufajo OO (1992) Response of soybean intercropping with maize on a sub-humid tropical environment. Trop Oilseed J 1:27–33

Oluwasemire KO, Stigter CJ, Owonubi JJ, Jagtap SS (2002) Seasonal water use and water yield of millet based cropping systems in the Nigerian Sudan Savanna near Kano. Agric Water Manag 56:207–227

Pilbeam CJ, Okalebo JR, Simmands LP, Gathua KW (1994) Analysis of maize-common bean intercrops in semi-arid Kenya. J Agric Sci Camb 123:191–198

Raddad EY, Luukkanen O (2007) The influence of different Acacia senegal agroforestry systems on soil water and crop yields in clay soils of the Blue Nile region, Sudan. Agric Water Managem 87:61–72

Rees DJ (1986) Crop growth, development and yield in semi-arid conditions in Botswana. II. The effects of intercropping *Sorghum bicolor* with *Vigna unguiculata*. Exp Agric 22:169–177

Rose CW, Adiku S (2001) Conceptual methodologies in agro-environmental systems. Soil Tillage Res 58:141–149

Rusinamhodzi L, Murwira HK, Nyamangara J (2006) Cotton-cowpea intercropping and its N2 fixation capacity improves yield of a subsequent maize crop under Zimbabwean rain-fed conditions. Plant Soil 287:327–336

Schmidhuber J, Tubiello FN (2007) Global food security under climate change. PNAS 104:19703–19708. http://pubs.giss.nasa.gov/docs/2007/2007_Schmidhuber_Tubiello.pdf

Snapp SS, Mafongoya PL, Waddington S (1998) Organic matter technologies for integrated nutrient management in smallholder cropping systems of southern Africa. Agric Ecosyst Environm 71:185–200

Stern KG (1984) Intercropping in tropical small-holder agriculture with special reference to West Africa. GTZ, Germany, 240pp

Stigter CJ, Baldy CM (1993) Manipulation of the microclimate by intercropping: making the best of services rendered. In: Sinoquet H, Cruz P (eds) Ecophysiology of tropical intercropping, INRA, Paris/Guadeloupe pp 29–44

Tsubo M, Mukhala E, Ogindo HO, Walker S (2003) Productivity of maize-bean intercropping in a semi-arid region of South Africa. Water SA 29:381–388

Tsubo M, Ogindo HO, Walker S (2004) Yield evaluation of maize-bean intercropping in a Semi-arid region of South Africa. Afr Crop Sci 12:351–358

Tsubo M, Walker S, Ogindo HO (2005) A simulation model of cereal–legume intercropping systems for semi-arid regions I. Model development. Field Crops Res 93:10–22

Walker S, Stigter CJ, Ofori E, Kyei-Baffour N (2011) Intercropping and its implications for soil management. In: Hatfield JL, Sauer TJ (eds) Soil management: building a stable base for agriculture. American Society of Agronomy, in press

Winarto YT, Stigter K, Anantasari E, Hidayah SN (2008) Climate field schools in Indonesia: coping with climate change and beyond. Low Ext Input Sust Agric (LEISA) Mag 24(4):16–18

WRI (2005) World Resources 2005: The wealth of the poor—managing ecosystems to fight poverty. World Resources Institute (WRI) in collaboration with the United Nations Development Programme, the United Nations Environment Programme and the World Bank. Washington, USA. http://www.wri.org/publication/world-resources-2005-wealth-poor-managing-ecosystems-fight-poverty

III.3.2.(iii) Detection of and Awareness on Increasing Climate Variability and the Elevating Climate Risk: Multiple Cropping

Kees Stigter

All socio-economic systems (especially climate-dependent systems such as agriculture, pastoralism, forestry, water resources, and human health) are continually in a state of flux in response to changing circumstances, including climatic conditions. Detection evidence and awareness evidence show that there is considerable potential for adaptation to reduce the impacts of climate change and to realize new opportunities. In China's Yangtze Valley, eighteenth-century regional expansions and contractions on the double cropping system for rice represented adaptive responses to the frequency of production successes and production failures associated with climatic variations (IPCC 2001). Change in climate risk patterns may include change in temperature, wind pattern, precipitation as well as change in frequency and magnitude of climate variability, particularly the extreme climate events (e.g. Stigter et al. 2005).

Studies indicate a high degree of spatial variability in the vulnerability of Asia/Pacific agriculture to climate change. Although increases in summer rainfall alone may benefit crop production and commercial forestry, particularly in South Asia (Preston et al. 2006), crop stress from rising temperatures may offset such benefits, particularly for (multiple cropping) rice yields (e.g. Stigter et al. 2007; Stigter et al. 2007). Investments must be made in increasing the capacity of Asia/Pacific nations to adapt to climate variability and the elevating climate risk.

From a small-scale resource poor farmer perspective in the developing countries, intercropping provides a strategy of risk aversion, livelihood sustainability, better nutrition and crop diversification (Walker et al. 2011). In their selection of changes in land use and cropping patterns, according to Rosset (1999), small-scale farmers are more likely to intercrop various crops on the same field, plant multiple times during the year, and integrate crops, livestock and even aquaculture, to make much more intensive use of space and time.

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision; Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_36,

To the small-scale resource poor farmer, multiple cropping serves to enhance risk avoidance regarding income, yield and ecological balance. From a commercial or large scale agriculture perspective in the developed countries, multiple cropping is practised to gain advantage of increased land productivity, maintenance of diversity, response to the effects of climate change, disease and pest control and ecosystem health (Walker et al. 2011).

Whilst the reality of impact of such features of global change as climatic change and CO_2 fertilization on agriculture are in no way diminished, it is an overarching principle that the manipulations introduced by the farmers – not only in response to these changes, but also with respect to the other factors which influence their activities – will prove to have the most significant effect on how multi-species agriculture changes over the next few decades (GCTE 1997). See also Box III.3.9.

Box III.3.9

Understanding or knowledge on how climate change may cause impacts at local scale is crucial for a long term adaptation plan that would minimize the impact or to better cope with future risks from climate change. A Multiple Cropping Center at Chiang Mai University, Thailand, is a leader in this work (START 2007). Intensive, multiple cropping and high occupation rates are normal agricultural practices in Egypt. More than 12 million acres of crops are cultivated annually on 6 million acres of land, giving an intensity index of 2. As to awareness, an assessment of the impacts of climate change on some crops has been advanced, but a detailed quantitative assessment of the impact of climate change on the agricultural sectors had not been carried out in Egypt 10 years ago (El-Raey 1998).

Improving agricultural cropping patterns (introduction of suitable drought tolerant crops, multiple cropping, crop rotation and diversification of crops) and homestead-based integrated farming (vegetable, horticulture, agroforestry, fruit gardening) are introduced by NGOs under drought conditions in northwest Bangladesh (SSN2 Project Portfolio 2006). In Malawi and Zimbabwe, panels of farmers define categories of production risk, acquaint themselves with strategies for coping with climatic risk at the farm level and identify climatic patterns that are difficult to manage. Scientists develop these strategies into scenarios that can be analyzed by simulation modeling of multiple cropping seasons. Results are presented to the farmer panels in demonstrations designed to generate debate about the relative attractiveness of a range of technical alternatives (ACIAR 2002).

References

ACIAR (2002) Risk management in southern African maize systems. http://www.aciar.gov.au/printable/project/LWR2/1997/038

El-Raey M (1998) Coastal zone development and climate change. Impact of climate change on Egypt. http://cesimo.ing.ula.ve/GAIA/CASES/EGY/impact.htm

GCTE (1997) Focus 3: Global change impact on agriculture, forestry and soils. http://www.gcte.org/ipf3.htm

IPCC (2001) Climate change 2001. Working Group II: Impacts, adaptation and vulnerability. http://www.grida.no/climate/ipcc_tar/wg2/647.htm

Preston B, Suppiah R, Macadam I, Bathols J (2006) Climate change in the Asia Pacific region. A consultancy report prepared for the Climate Change and Development Roundtable. CSIRO Marine and Atmospheric Research. http://www.csiro.au/csiro/content/file/pfkd.html

Rosset PM (1999) The multiple functions and benefits of small farm agriculture in the context of global trade negotiation, Institute for Food and Development, Policy brief #4. http://www.foodfirst.org/pubs/policybs/pb4.pdf

SSN2 Project Portfolio (2006) Bangladesh, Adaptation: CARITAS (Chapai) Drought Project. http://www.southsouthnorth.org/country_home.asp?country_id=11

START (2007) Southeast Asia START Regional Center and climate change study. http://research.start.or.th/climate/index.php?option=com_content&task=view&id=12&Itemid=1

Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005) Using traditional methods and indigenous technologies for coping with climate variability. Clim Change 70:255–271

Stigter K (2007) New cropping systems to help farmers. Jakarta Post, January 22, p7

Stigter K, Das H, Nguyen Van Viet (2007) On farm testing of designs of new cropping systems will serve Indonesian farmers. Available on the INSAM website under “Needs for agrometeorological solutions to farming problems” of 16 January

Walker S, Stigter CJ, Ofori E, Kyei-Baffour N (2011) Intercropping and its implications for soil management. In: Hatfield JL, Sauer TJ (eds) Soil management: building a stable base for agriculture. American Society of Agronomy, in press

III.3.2.(iv) (Changes in) Adaptation Strategies to Climate Changes: Multiple Cropping

Kees Stigter

Under agriculture as key areas for adaptation to climate change in China, one issue was explicitly to promote adjustment of agricultural structure and cropping systems. It was proposed to extend the planting areas of economic and forage crops, and promote the shift of the structure of cropping systems from a dual structure with food crop and cash crop to a ternary structure with food crop, cash crop and forage crop. This way cropping systems were adjusted, developing multiple cropping and raising multiple cropping indexes. Furthermore, all walks of life of the society would be fully employed to disseminate China's efforts and policies for response to climate change and to promote public awareness of climate change (Pan 2007).

An overview of farmer adaptation to changing climate in Zimbabwe (Mano and Nhemachena 2007) that is very representative for Africa indicates that farmers are already using some adaptation strategies. These are dry and early planting, growing drought resistant crops, changing planting dates, applying multiple cropping – that includes changing crop mixtures – and using irrigation, to cushion themselves against further anticipated adverse climatic conditions.

An important policy message from the empirical findings is that there is a need to provide adequate extension information services to ensure that farmers receive up-to-date information about rainfall patterns in the forthcoming season, so that they make well-informed decisions on their planting dates (see also Stigter 2007a; Winarto et al. 2008 for Asian examples and the use of Farmer Field Schools in such undertakings). Policies that increase farmer training and access to credit and other important farm assets can help improve net farm performance (Mano and Nhemachena 2007).

Such outcomes confirm that adaptation to climate change is just part of the general development issues (e.g. Salinger et al. 2000; Stigter 2008a) exemplified in response farming the way this applies already for decades, including the need for inclusion of

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_37,

the multiple cropping issue (Stigter 2008b; Stigter and Abdoellah 2008). It should always be local windows of opportunity that have to be researched in a participative approach to combat land degradation, again with much multiple cropping involved (Stigter et al. 2005).

Detailed examples of the latter as agroforestry adaptations and innovations under humid (Stigter 2007b; Stigter and Abdoellah 2008) and dry (Oteng'i et al. 2007a, b) conditions were recently given. Confirmation can also be found in IISD (2006), Srinivasan (2004) and Mendelsohn and Dinar (1999), the latter already confirming that farmers do adapt. Another good example of this is in Box III.3.10. Such newly designed systems, which designs must also be seen as agrometeorological services (WMO 2010), can face climate change as well.

Box III.3.10

According to Chris Geerling (pers comm 2008) from the Working Group on Ecology and Development of the Netherlands Commission on International Nature Conservation, the wide ranges of (Low External Input) farming systems found in Africa – but the same applies to great parts of Latin America and Asia – is a reflection of the range of variation in the nature and the availability of the natural, economic and human resources, under widely varying geographical, climate, governance and political conditions. Geerling states that farming systems under these conditions mean playing the given deck of a whole series of low-value cards, with risk reduction as the main operative, rather than maximalisation of production. Adaptation strategies to climate change have to be of that same kind in these regions (Stigter 2007b).

Slash and burn agriculture contains several of such farming systems in which coping with risk reduction by farmers destroys forests. This is widely believed to contribute to climate change (see also for example Stigter and Abdoellah 2008). In such systems the soil quickly becomes infertile. In an example on the acid soils of the Costa Rican rain forest this was already the case after 2 years (Elkan 2005, 2006). According to this author, based on research by the British tropical ecologist Mike Hands, alley cropping with *Inga edulis* is an agroforestry solution for such farmers in Costa Rica, Honduras and elsewhere that will make it possible to get into (more) sedentary farming as an alternative to slash and burn farming. It is the merit of Hands' work that it first determined in a participatory approach with the Costa Rican farmers the problems of weed infestation and fast loss of productivity after slash and burn had taken place (Elkan 2005, 2006). They were clearly in need of an alternative. It is another merit of Hands' work that he found the lack of phosphorus to be the main limiting soil factor due to fast leaching from the soil after slash and burn (Elkan 2005, 2006). See also Box III.3.6 in Sect. III.3.1.(f).

References

Elkan D (2005) The rainforest saver. The Ecologist, ECOLOGISTONLINE. http://www.theecologist.co.uk/archive_detail.asp?content_id=424

Elkan D (2006) An alternative to slash and burn. In: Farming matters: understanding sustainable agriculture. Low Ext Input Sust Agric (LEISA) Mag Special Issue: 15–16

IISD (2006) UNFCC African Regional Workshop on Adaptation (ARWA). ARWA Bull, 2(1). http://www.iisd.ca/africa/vol02/arc0201e.html

Mano R, Nhemachena C (2007) Assessment of the economic impacts of climate change on agriculture in Zimbabwe: a Ricardian approach. Policy Research Working Paper 4292. World Bank, Washington. http://ideas.repec.org/p/wbk/wbrwps/4292.html

Mendelsohn R, Dinar A (1999) Climate change, agriculture, and developing countries: does adaptation matter? World Bank Res Obser 14:277–293. http://www.worldbank.org/research/journals/wbro/obsaug99/article6.pdf

Oteng'i SBB, Stigter CJ, Ng'ang'a JK (2007a) Understanding maize/beans intercropping yield distributions from water conservation measures in a hedged agroforestry system in semi-arid Laikipia District, Kenya. J Sci Technol Educ Manag (JSTEM) 1:6–33

Oteng'i SBB, Stigter CJ, Ng'ang'a JK, Liniger H-P (2007b) Soil moisture and its consequences under different management in a six year old hedged agroforestry demonstration plot in semi-arid Kenya, for two successive contrasting seasons. Afr J Agric Res 2:89–104

Pan L (ed) (2007) Press Conference on Climate Change Program. http://english.gov.cn/2007-06/04/content_636052.htm

Salinger JJ, Stigter CJ, Das, HP (2000) Agrometeorological adaptation strategies to increasing climate variability and climate change. Agric For Meteorol 103:167–184

Srinivasan A (2004) Local knowledge for facilitating adaptation to climate change in Asia and the Pacific: policy implications. IGES-CP Working Paper 2004-002. http://www.iges.or.jp/en/cp/pdf/report8.pdf

Stigter K (2007a) An account of visiting those involved in climate field schools in Indonesia. Available at the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology". Also used as Appendix II in Stigter K (2008b)

Stigter K (2007b) *Inga* alley cropping as an agrometeorological service to slash and burn farmers. Available at the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology". Also used as Appendix I in Stigter K (2008b)

Stigter K (2008a) Panta rhei: changes in agrometeorological adaptation strategies to climate change. First Keynote Lecture at the Opening Session of the Combined Conference of the South African Society of Crop Production, the Soil Science Society of South Africa, the Southern African Society for Horticultural Sciences and the Southern African Weed Science Society. Grahamstown, 22 January

Stigter K (2008b) Coping with climate risks in agriculture needs farmer oriented research and extension policies (based on participation, preparedness and resilience). Paper Presented at the First Venezuelan Agrometeorology Congress, San Cristobal, November 2007. Scientia Agricola (Piracicaba, Brazil), 65(special issue), pp 108–115. http://www.scielo.br/pdf/sa/v65nspe/a16v65nsp.pdf

Stigter K, Abdoellah S (2008) Cocoa and climate change, can the lame help the blind? Invited Paper Presented at the "2008 Indonesian Cocoa Symposium", Organized by ICCRI, Jember, at Sanur. An updated version is available at the INSAM website (www.agrometeorology.org) under "Needs for agrometeorological solutions to farming problems" of 3 November

Stigter CJ, Oteng'i SBB, Oluwasemire KO, Al-Amin, NKN, Kinama JM, Onyewotu LOZ (2005). Recent answers to farmland degradation illustrated by case studies from African farming systems. Ann Arid Zone 44:255–276

Winarto YT, Stigter K, Anantasari E, Hidayah SN (2008) Climate Field Schools in Indonesia: coping with climate change and beyond. Low Ext Input Sust Agric (LEISA) Mag 24 (4):16–18

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by C.J. Stigter. WMO, Geneva, in press

III.3.3 Coping with Extreme Meteorological Events

III.3.3.(A) Problems and Solutions in Coping with Extreme Meteorological Events in Agricultural Production, and Challenges Remaining for the Use of Science to Contribute to Problem Analyses and Designing Valuable Solutions in This Context: Multiple Cropping

Kees Stigter

In Chap. III.1, multiple cropping systems relevant to this section have been discussed. Understanding on the phenomena, impacts, actions, problems, solutions and policies related to priority extreme meteorological events that cause farmers and their local governments the largest difficulties in multiple cropping in a region may, with the exception of the phenomena, be supposed to be different from those in monocropping by the same category of farmers (see Sect. III.2.3.(A)). The issue to attend to here appears to be what multiple cropping systems have as defence strategies to extreme meteorological events that are less efficient or not available in monocropping and what science can contribute to understanding and developing such strategies.

It was argued already quite some time ago that "funding organizations have too often failed to see the importance of multiple cropping micrometeorology in combating the on-farm damaging effects of meteorological hazards in low external input agricultural production in Africa and elsewhere" (Stigter et al. 1991). Ten years later WMO (2001), using proposals by Salinger et al. (2000), advocated as solutions institutionalized long term "weather advisories on farming, production and cropping systems, in accordance with the possibilities for change in the different farming communities", applying "to techniques of using inputs, soil conditions and planting densities, choices of cropping systems and varieties".

In addition other response farming extension "through on-line current advisories, on time scales and in space scales as required" would be necessary, exemplified by

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_38,

"weather and climate forecasts and timely advices on farm operations such as sowing dates, weeding, fertilizing, spraying, integrated pest management, harvesting and drying" (Salinger et al. 2000; WMO 2001). Irrigation is of course since long part of this range (e.g. Lomas and Levin 1979).

However, where such knowledge is operational at all in agrometeorological services, it is mainly for monocropping (e.g. Stigter 1999, 2006c), perhaps for sequential cropping (e.g. Brown 2003), but it remains marginal for mixed (inter)cropping and relay (inter)cropping (Stigter and Baldy 1993), with the exception of the long recognized but insufficient exploited protection functions of trees in agroforestry applications (e.g. Stigter 1988).

Long experience of uncertainty about weather patterns has induced farmers in rainfed subsistence economies such as in Africa to develop complex cultigen repertoires and cultivar mixtures to ensure yields under all conditions. Such practice necessarily yields less than monocropping productive races under good conditions but yields better under the frequently occurring adverse conditions (Blench and Marriage 1998). Replacing multiple crops with monocropping may raise demand for external inputs and increase pressure on the soil. Suitable socio-economic and policy environments to maintain and improve soil fertility may be lacking (DFID 2002). After decades of monocropping using traditional slash and burn methods, a growing interest in intercropping and crop sequencing to overcome drought in Asia and the Pacific region has emerged (FAO 2001a).

A first important issue in this context is the observation of Blench (1999) that rainfall patchiness (dry spells as a serious short term drought pattern) and rainfall intensity are more important weather/climate forecast informations to most farmers than the usually available forecasts, but that they are hardly available as such. In this context important factors of intercropping may be protection against extreme temperatures and surface soil drying by shading and mulching and against drop impact and leaching by rainfall interception and mulching (e.g. Baldy and Stigter 1997; Stigter 2007). Quantification of intercropping systems has a role to play in understanding such factors better for problem analyses and the design of improved solutions (e.g. Mungai et al. 2000; Stigter 2007).

The same applies to the other relatively short-term extreme meteorological events in agricultural production listed in Sect. III.2.3.(A), floods and tropical storms, tornadoes and strong winds. Due to the meagre existing multiple cropping literature related to floods, collected by Stigter et al. (2003), green belts are known to reduce the impact of flooding, and beneficial vegetation in flood-hazard areas and/or upstreams is preserved or improved by reforestation or by erosion and flood preventing growings of grasses and trees/bushes on hill slopes and terrace raisers. Das (2005) describes a livelihood strategy case study from Bangladesh involving water friendly plants/trees. Multiple cropping literature on protection from strong winds and their effects is somewhat more abundant and has mainly to do with microclimate manipulation using forestry and non forest trees. An example of risks from wind damage provoked by changing multiple cropping food gardens into monocropping on Pacific islands is discussed in FAO (2001b). Review literature, including scientific aspects, is in Onyewotu et al. (2004) and Rathore and Stigter (2007), while livelihood aspects may be found in Onyewotu et al. (2003).

Such livelihood literature (see also Box III.3.11) is again rare in agrometeorology. Overall there has been little progress in reducing risk levels (Maunder and Wiggins 2007). This includes climatic risks in agriculture from extreme events not only in Africa (Stigter 2006a) but even in India, with the exception of choices of more suitable varieties and plant population management (Das 2005). In this same series of ODI-papers, many facets of this general conclusion on risks are explained in detail as to pro-poor agricultural extension (Farrington et al. 2002), low external input agriculture (Tripp 2007), poverty reduction strategies (Cabral 2006), pro-poor agricultural policies (Dorward et al. 2004), decentralized natural resources management (Baumann and Farrington 2003), agricultural technology (Tripp 2003) and poverty reduction, equity and climate change (Richards 2003). The last subject also Stigter (2006b) and Lemos and Dilling (2007) dealt with more recently.

Box III.3.11

Sometimes one misses a study from another field of science that matches one's own experiences and that one regrets not having seen earlier. Doing literature search for this book, in the context of challenges remaining for the use of science to contribute to problem analyses and designing valuable solutions, this was the case with Chambers (1990). Of course the author of "Rural development: putting the last first" (Chambers 1983), "Farmer first: farmer innovation and agricultural research" (Chambers et al. 1989a), "To the hands of the poor: water and trees" (Chambers et al. 1989b) and "Trees to meet contingencies: savings and securities for the rural poor" (Chambers and Leach 1989) was known to me through his work. But his "Microenvironments unobserved" (Chambers 1990) struck me as a microclimatologist, who worked on quantifying farmer microenvironments (see among others Chap. IV.9) since the early eighties in Africa and who advocated such work in Asia since the late eighties and early nineties in theory (Stigter 1994a) and practice (Stigter 1994b), as arising from the same realm of experience and thinking (see also Stigter et al. 1991; Stigter and Baldy 1993; Baldy and Stigter 1997). This sensation I had only felt earlier with the work of Wilken (1972, 1987) and Baldy (1986) and still feel of course with much that is published by what now is called the Low External Input Sustainable Agriculture (LEISA) Magazine, to which I have contributed in these fields since almost its establishment, over more than 20 years (e.g. Stigter 1987; Winarto et al. 2008).

Chambers (1990) has stated that the "transfer of technology" paradigm has been increasingly questioned, even in the citadels of normal professionalism. Reductionist research, high input packages and top-down extension have had their successes: in the uniform and controlled conditions of industrial and green revolution agriculture they have raised output per unit of land. But the sustainability of that increase is open to question and the transfer of technology does not work well with the more complex, diverse and risk-prone rainfed agriculture of much of the poorer South (Chambers 1990), including multiple cropping as an approach to these problems. Explanations of non-adoption are for more than two decades now increasingly sought in the technology itself, the concept of package and the process whereby the technology is generated. A green revolution for the poor is in need of other science and other education and extension (KNMI 2009). This book wants to make a contribution into that direction.

The general biases in both agricultural and social sciences combine to hide microenvironments from sight, to understate or exclude them in statistics, and to undervalue their importance for livelihoods. In this context a microenvironment is a distinct small-scale environment which differs from its surroundings, presenting sharp gradients or contrasts in physical conditions internally or externally. They can be isolated, or contiguous and repetitive, and natural or made by people or domestic animals (Chambers 1990). Examples from our African work may be found in Mohammed et al. (1999), Kainkwa and Stigter (2000), Mungai et al. (2000), Stigter et al. (2000), Onyewotu et al. (2004), Kinama et al. (2005) and Oteng'i et al. (2007). It is understandable that these examples all come from agroforestry conditions, where these microclimate gradients are most obvious, but in the context of multiple cropping we also can produce another example (Oluwasemire et al. 2002). Where modeling such conditions remains a challenge, combinations of measurements and modeling, that have been so successful in understanding monocropping and forest microclimates 30 years ago, could also here bring improvements (e.g. Stigter et al. 1977; Stigter 1994a; Chap. IV.9).

References

Baumann P, Farrington J (2003) Decentralising natural resource management: lessons form local government reform in India. Natural resources perspectives 86, ODI, London

Baldy C (1986) Agrometeorologie et developpement des regions arides et semiarides. [Agrometeorology and the development of dry and semiarid areas.] INRA, Paris, 114pp

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Blench R (1999) Seasonal climate forecasting: who can use it and how should it be disseminated? Natural resources perspectives 47, ODI, London, 4pp. http://dlc.dlib.indiana.edu/archive/00004392/01/86-decentralising-natural-resource-management-india.pdf

Blench R, Marriage Z (1998) Climatic uncertainty and natural resource policy: what should the role of government be? Natural resources perspectives 31, ODI, London, 10pp. http://dlc.dlib.indiana.edu/archive/00005065/01/31-climatic-uncertainty-and-natural-resource-policy.pdf

Brown LR (2003) Plan B: rescuing a planet under stress and a civilization in trouble. W.W. Norton & Co., New York. http://www.earth-policy.org/Books/PB/PBch8_ss3.htm

Cabral L (2006) Poverty reduction strategies and the rural productive sectors: what have we learnt, what else do we need to ask? Natural resources perspectives 100, ODI, London, 4pp. http://www.odi.org.uk/resources/download/109.pdf

Chambers R (1983) Rural development: putting the last first. Longman, Harlow, UK. http://www.id21.org/classics/Chambers.html

Chambers R (1990) Microenvironments unobserved. International Institute for Environment and Development Gatekeeper Series SA22, London, 19pp

Chambers R, Leach M (1989) Trees to meet contingencies: savings and security for the rural poor. World Dev 17:329–432

Chambers R, Pacey A, Thrupp LA (eds) (1989a) Farmer first: farmer innovation and agricultural research. Intermediate technology publications, London, 219pp

Chambers R, Saxena NC, Shah T (1989b) To the hands of the poor: water and trees. Oxford and IBH, New Delhi, and IT Publications, London, 273pp

Das HP (2005) Agrometeorological impact assessment of natural disasters and extreme events and agricultural strategies adopted in areas with high weather risks. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 93–118

DFID (2002) Soil fertility and nutrient management. ODI Keysheet – Resource Management No. 7. http://www.keysheets.org/green_7_soils.pdf

Dorward A, Fan S, Kydd J, Lofgren H, Morrison J, Poulton C, Rao N, Smith L, Tchale H, Thorat S, Urey I, Wobst P (2004) Rethinking agricultural policies for pro-poor growth. Natural resources perspectives 94, ODI, London, 4pp. http://www.odi.org.uk/resources/download/620.pdf

FAO (2001a) Developing farming systems and best practices for drought-prone areas. Report of the FAO Asia-Pacific Conference on Early Warning, Prevention, Preparedness and Management of Disasters in Food and Agriculture. RAP 2001/14, Annex XIV, APDC/01/10. http://www.fao.org/docrep/005/AC120E/AC120e00.HTM

FAO (2001b) Reducing agricultural vulnerability to storms, with special reference to farming systems and methods. Report of the FAO Asia-Pacific Conference on Early Warning, Prevention, Preparedness and Management of Disasters in Food and Agriculture. RAP 2001/14, Annex XI, APDC 01/07. http://www.fao.org/DOCREP/005/AC120E/AC120e12.htm

Farrington J, Christoplos I, Kidd A, Beckman M, with Cromwell E (2002) Creating a policy environment for pro-poor agricultural extension: the who? what? and how? Natural resources perspectives 80, ODI, London, 4pp. http://www.odi.org.uk/resources/download/2060.pdf

Kainkwa RMR, Stigter CJ (2000) Measuring wind gradients in agroforestry systems by shaded Piche evaporimeters I. Validation of the square-root dependence on wind speed. Int Agrophys 14(3):279–289

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2005) Evaporation from soils below sparse crops in contour hedgerow agroforestry in semi-arid Kenya. Agric For Meteorol 130:149–162

KNMI (for Netherlands Government, compiled by Kees Stigter, second update, 2009) Capacity building in the area of agrometeorological services through roving seminars. Document originally distributed and presented as CAgM-XIV/INF. 4 at the XIVth Session of the WMO CAgM, New Delhi, October/November 2006, 13pp

Lemos MC, Dilling L (2007) Equity in forecasting climate: can science save the world's poor? Sci Publ Pol 34:109–116

Lomas J, Levin J (1979) Irrigation. In: Seemann J, Chrirkov YI, Lomas J, Primault B (eds) Agrometeorology. Springer, Berlin/Heidelberg/New York, pp 217–264

Maunder N, Wiggins S (2007) Food security in Southern Africa: changing the trend? Review of lessons learnt on recent responses to chronic and transitory hunger and vulnerability. Natural resources perspectives 106, ODI, London, 4pp. http://www.odi.org.uk/resources/download/114.pdf

Mohammed AE, Stigter CJ, Adam HS (1999) Wind regimes windward of a shelterbelt protecting gravity irrigated crop land from moving sand in the Gezira Scheme (Sudan). Theor Appl Climat 62:221–231

Mungai DN, Stigter CJ, Coulson CL, Ng'ang'a JK (2000) Simply obtained global radiation, soil temperature and soil moisture in an alley cropping system in semi-arid Kenya. Theor Appl Climatol 65:63–78

Oluwasemire KO, Stigter CJ, Owonubi JJ, Jagtap SS (2002) Seasonal water use and water yield of millet based cropping systems in the Nigerian Sudan Savanna near Kano. Agric Water Manag 56:207–227

Onyewotu L, Stigter K, Abdullahi Y, Ariyo J (2003) Shelterbelts and farmers' needs. Low Ext Input Sust Agric (LEISA) Mag 19(4):28–29

Onyewotu LOZ, Stigter CJ, Oladipo EO, Owonubi JJ (2004) Air movement and its consequences around a multiple shelterbelt system under advective conditions in semi-arid northern Nigeria. Theor Appl Climatol 79:255–262

Oteng'i SBB, Stigter CJ, Ng'ang'a JK, Liniger H-P (2007) Soil moisture and its consequences under different management in a six year old hedged agroforestry demonstration plot in semi-arid Kenya, for two successive contrasting seasons. Afr J Agric Res 2(3):89–104

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties in Asian regions. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 53–69

Richards M (2003) Poverty reduction, equity and climate change: challenges for global governance. Natural Resources Perspectives 83, ODI, London, 4pp. http://www.odi.org.uk/resources/download/2058.pdf

Salinger JJ, Stigter CJ, Das, HP (2000) Agrometeorological adaptation strategies to increasing climate variability and climate change. Agric For Meteorol 103:167–184

Stigter CJ (1987) Traditional manipulation of microclimatic factors: knowledge to be used. ILEIA Newsl 3(3):5–6

Stigter CJ (1988) Microclimate management and manipulation in agroforestry. In: Wiersum KF (ed), Viewpoints on agroforestry, 2nd edn. Agricultural University, Wageningen, pp 145–168

Stigter CJ (1994a) Micrometeorology. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York, pp 59–72

Stigter CJ (1994b) Management and manipulation of microclimate. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York, pp 273–284

Stigter CJ (1999) The future of agrometeorology: perspectives in science and services. WMO-Bull 48:353–359

Stigter K (2006a) Scientific research in Africa in the 21st century, in need of a change of approach. Afr J Agric Res 1:4–8

Stigter K (2006b) Equity climate for all. INSAM website under "Agromet Market Place". www.agrometeorology.org

Stigter K (2006c) Agrometeorological services in various parts of the world, under conditions of a changing climate. Austin Bourke Memorial Lecture presented in the Royal Irish Academy, Dublin. Extended Abstract on the INSAM website under "Accounts of Operational Agrometeorology". www.agrometeorology.org

Stigter K (2007) *Inga* alley cropping as an agrometeorological service to slash and burn farmers. Available at the INSAM website under "Accounts of Operational Agrometeorology". www.agrometeorology.org

Stigter CJ, Baldy CM (1993) Manipulation of the microclimate by intercropping: making the best of services rendered. In: Sinoquet H, Cruz P (eds) Ecophysiology of tropical intercropping, INRA, Paris/Guadeloupe, pp 29–44

Stigter CJ, Goudriaan J, Bottemanne FA, Birnie J, Lengkeek JG, Sibma L (1977) Experimental evaluation of a crop climate simulation model for Indian corn (Zea Mays L.). Agric Meteorol 18:163–186

Stigter CJ, Baldy C, Coulson CL, Othieno CO, Mohammed AE, Mungai DN, Kainkwa RMR, Ibrahim AA (1991) Meteorological hazards and the low external input farmer: some case studies. In: Oguntoyinbo JS, Omotosho JB, Ekuwem EE (eds), Meteorological hazards and development, Kola Okanlawon Publ, Lagos, pp 59–64

Stigter CJ, Kainkwa RMR, Oteng'i SBB, Onyewotu LOZ, Mohammed AE, Ibrahim AA, Rashidi MGM (2000) Measuring wind gradients in agroforestry systems by shaded Piche evaporimeters II. Accuracies obtained in some African case studies. Int Agrophys 14:457–468

Stigter CJ, Das HP, Murthy VRK (2003) Beyond climate forecasting of flood disasters. Invited Lecture on the Opening Day of the Fifth Regional Training Course on Flood Risk Management (FRM-5) of the Asian Disaster Preparedness Center (Bangkok) and the China Research Center on Flood and Drought Disaster Reduction (Beijing), Beijing, September. Available from ADPC (Bangkok) on CD-ROM. Also available at http://www.agrometeorology.org/fileadmin/insam/repository/ADPC2mp.pdf

Tripp R (2003) The enabling environment for agricultural technology in sub-Saharan Africa and the potential role of donors. Natural Resources Perspectives 84, ODI, London, 4pp. http://www.odi.org.uk/resources/download/1239.pdf

Tripp R (2007) Is low external input technology contributing to sustainable agricultural development? Rural Dev News 2:5–10. http://www.agridea-international.ch/fileadmin/10_International/PDF/RDN/RDN_2007/01_Low_external_input.pdf

Wilken GC (1972) Microclimate management by traditional farmers. Geogr Rev 62:544–566

Wilken GC (1987) Good farmers. Traditional agricultural resource management in Mexico and Central America. University of California Press, Berkely, 302pp

Winarto YT, Stigter K, Anantasari E, Hidayah SN (2008) Climate Field Schools in Indonesia: coping with climate change and beyond. Low Ext Input Sust Agric (LEISA) Mag 24(4):16–18

WMO (2001) Weather, climate and food security. WMO 933, Geneva, 24pp

III.3.3.(B) Designing and Selecting Early Warning Strategies and Increasing Their Efficiencies: Multiple Cropping

Sue Walker and Kees Stigter

When designing early warning strategies, one has to understand the climate, the agriculture and the social or livelihoods aspects of the area. Therefore one must have a good idea of what climate/weather information, products and services are available, so that their applications can be further developed and utilized in the early warning service. Then the current status of the stakeholders or community and their agricultural production systems should also be well understood, so that one can identify the opportunities. This can be done using the livelihood profiles and livelihoods baselines (see for example www.fews.net) and a range of options – including farming system options – available to the people, whether at a household, a community or a national/regional level.

However, what is critical is to be able to understand and to predict the future weather or climatic conditions that can push the households towards the critical hunger level. So, part of the design process must be to characterize the vulnerability and identify for each group specific characteristics that lead them to be more or less susceptible to the extreme climate event (Dilley and Boudreau 2001). If these characteristics can be monitored and evaluated, of course as specific for each of their farming systems, then the impacts of variable or changing weather and climate conditions on the livelihoods and farming systems can be identified.

Visualization methods from the agro-ecosystem analysis (Catley et al. 2002) can be used, with the communities, to identify local perceptions of seasonal variations and identify critical periods or sensitive periods that are related to specific weather parameters. Through such participatory methodologies one can then address a set of local risks through the eyes of the users (Erikson and Silva 2009). This then makes it possible to include information about the currently used multiple cropping systems from the small-holders and how they can envisage incorporating the early warning information into their farming systems.

S. Walker (✉)
Department of Soil, Crop and Climate Sciences, University of the Free State, Bloemfontein, South Africa
e-mail: walkers.sci@ufs.ac.za

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_39,

The high risk processes or high risk situations can then be analyzed using a multiple criteria decisions analysis (Pietersen 2006). The chain of reactions or logical decisions needs to be analyzed within the social, resource base and farming system context. This helps to identify the major objectives of the users and also identify the alternative decisions paths (Pietersen 2006). For this problem structuring, one needs to conduct technical and social field investigations preferably in pilot or case study areas. This information is then used to trace the critical path of decisions, particularly those that are sensitive to the weather and climate (Archer et al. 2007).

These climate sensitive decisions can be at various levels in the system (at a field or farm level or at a ward or district or state level or at national or regional level) (e.g. Walker 2007). They are often well-known to the locals but have often not been documented through history by the most relevant disciplines. There also needs to be follow-up to assess the relevance of forecasts to that specific decision (e.g. Meinke et al. 2006). As the ultimate aim is to maintain sustainable livelihoods, all stakeholders should be involved in the various processes and stages.

Many times a range of interventions or alternative technologies could be made available and a comprehensive list needs to be formulated for each of the climate sensitive decisions. This list should include diverse opportunities for the whole range of systems and be flexible in design as well as institutional requirements (Erikson and Silva 2009). The interventions can be a change in or further diversification of crops in the use of multi-cropping systems to optimize the use of available resources and to promote productivity.

Once the problem has been decomposed, a decision-making framework can be developed to include the interrelationships of the various factors and attributes that are associated with the various alternative decisions (Pietersen 2006). The logical sequential steps need to be developed for the specific early warning system in such a way that the following factors are included

- technical and institutional assessments;
- identification of appropriate technology options;
- a range of technically feasible options from the available climate inputs; and
- a range of implications for the community/agricultural systems/water resources management.

The selection criteria for the information to be used in the early warning systems should ideally include the reliability, accuracy and uncertainty of the predictions; the relevance and usefulness of the information; ease with which it can be understood and effectively used as well as the sensitivity of the operations to climate or weather anomalies. It is here that efficiencies can be particularly improved, including the use of multiple cropping systems, either intercropping, or agroforestry or sequential cropping, that had not been previously used or given attention to in the particular region.

Schneider and Garbrecht (2003) defined usefulness as "the ability of the forecasts to predict conditions significantly different from climatological norms". However, this usefulness, even in one location, will also vary with the season and lead time as well as the specific state of the atmosphere and sensitivity of the indicators. So even if seasonal precipitation forecasts can be shown to be dependable and effective, individual, local agricultural planners and managers may find limited usefulness in certain regions and at lead times where forecasts rarely depart from climatology (Schneider and Garbrecht 2003).

In addition to the information being relevant, it must also be reliable, or early warnings could cause excessive damages. As most long range forecasts are in a probabilistic format, it is difficult to quantify the reliability unless a long archived record is available. The quantification of uncertainty should also result in projected ranges, and possibly probabilities, that accurately reflect reality (Challinor 2009). As one wants to provide the best possible quality of information to decision makers, the suppliers should make every effort to obtain as high as possible accuracies of the forecasts (Challinor 2009). However, testing some of these is not very easy, as the models and forecasts are most often at different scales compared to the observations or measurements available. Some general issues and practical aspects of early warnings are discussed in Boxs III.3.12 and III.3.13 respectively.

The seasonal forecast is discussed in Box III.3.14. Efficiencies that count will only be obtained when the dissemination to and use by farmers is more fully and better addressed. In the southern province of Zambia there is good communication of the seasonal forecast to the smallholders at district and ward level. The seasonal and regular 10-day bulletins are issued by the Zambian Meteorology Department and then disseminated by the agrometeorologists. This has been made possible by continued involvement of the Zambian Department of Agriculture extension personnel at the district and ward level. This team then holds regular community meetings and weekly broadcasts on weather/agriculture related topics by the local radio station in Monze. The small-holders have learnt how to interpret and use the available climate information when deciding on which lands to plant each season and which cultivar to choose according to the rainfall outlook. This was further enhanced by the community modeling exercise in which a crop simulation model was used to illustrate the effect of different fertilizer applications in seasons with high or low rainfall (Walker et al. 2009).

Box III.3.12

As extreme climate events and hazards can cause much damage and high losses, advance warnings on time scales of months to years would be most useful for planning agricultural strategies and on time scales of hours to days for immediate responsive operations or action. However, they cannot only be comprised of the typical detailed weather forecast, as the information usually needs to be disseminated and acted on as quickly as possible to avoid disaster. The advisories should also include user specific information and some suggestions as to possible interventions or actions to be taken. For multiple cropping systems such information should apply to these systems and interventions/actions for such systems. This means that it is vital that good data bases are available together with skilled multi-disciplinary (extension) teams and backed up by good co-operation between scientists, extensionists and end-users or practitioners (Ogallo et al. 2000).

Box III.3.13

In practice an effective early warning system must include a database and a geographical information system (GIS) as well as calibrated models for the region (de Jager et al. 1998). Usually the models will use ENSO forecast information (SSTs & SOIs) from the global climate models run by the international centers, together with a crop simulation model to predict the yields for the next season. At present the Global Forecasting Centre for Southern Africa (GFCSA) provides a website where the long-range global forecasts produced by institutions within southern Africa are freely available (www.gfcsa.net). For the success of such a system one needs to address the actual technologies as well as both the policy and institutional aspects (Thomas 2008). So, any new system should be built on the existing National Meteorological and Hydrological Services (NMHSs) and the coping strategies that the farmers already have in place for their respective agricultural production systems. Key components include the access to resources, information and technology as well as the skill and knowledge of how to use them (Thomas 2008). Linkages between the public and private sector and the stability of the economy, and efficiencies of social and government institutions also have an impact on the effectiveness of any system. Probably, the systems would be best managed and operated at a national level, with specific actions divulged to a lower operational level, as this could then form part of the responsibility of the NMHS. Time and again it should be considered whether efficiencies of the early warning systems can be improved. The dissemination and distribution of the advisories should be efficient down to the grass-root level of the public and specific interest groups.

Box III.3.14

In southern Africa early warning systems have been in operation for a number of years. Most of the systems are linked to the frequent occurrence of drought and famine in the region (Archer et al. 2007). The Southern African Regional Climate Outlook Forum (SARCOF) has been held since the late 1990s and brings together meteorologists form the Southern African

Development Community (SADC) countries. Then using long-term climate data and the current ENSO signal with long range forecast or predictions from the international climate research labs, e.g.
IRI (www.iri.columbia.edu/climate/forecast/net_asmt/),
ECMWF (www.ecmwf.int/products/forecasts/d/charts/seasonal/forecast/eurosip/),
NCEP (www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/ensoforecast.shtml),
NOAA etc,
they formulate a 3-category probabilistic seasonal forecast for the two 3-month periods of the southern hemisphere summer rainfall season (IRI 2000). The regional outlook is used by the international aid organizations such as World Food Program (WFP) and World Vision to assess the potential for a shortage of food during the forthcoming season. However, there is only a weak dissemination of this capacity down to a national level, to the National Early Warning Units (NEWUs), although this varies across SADC countries. Dissemination to and use by farmers most often leaves very much to be desired (Hellmuth 2007; Stigter 2008).

References

Archer E, Mukhala E, Walker S, Dilley M, Masamvu K (2007) Sustaining agricultural production and food security in Southern Africa: an improved role for climate prediction? Clim Change 83:287–300

Catley A, Osman J, Mawien C, Jones BA, Leyland TJ (2002) Participatory analysis of seasonal incidences of disease of cattle, disease vectors and rainfall in southern Sudan. Prevent Vet Med 53:275–284

Challinor AJ (2009) Developing adaptation options using climate and crop yield forecasting at seasonal to multi-decadal timescales. Environ Sci Policy 12:453–465

De Jager JM, Potgieter AB, van den Berg WJ (1998) Framework for forecasting the extent and severity of drought in maize in the Free State Province of South Africa. Agric Syst 57:351–365

Dilley M, Boudreau TE (2001) Coming to terms with vulnerability: a critique of the food security definition. Food Pol 26:229–247

Erikson S, Silva JA (2009) The vulnerability context of a savanna area in Mozambique: household drought coping strategies and responses to economic change. Environ Sci Pol 12:33–52

Hellmuth ME, Moorhead A, Thomson MC, Williams J (eds) (2007) Climate risk management in Africa: learning from practice. International Research Institute for Climate and Society (IRI), Columbia University, New York, 105pp

IRI (2000) Coping with the climate: a way forward. In: Summary and proposals for action from a multi-stakeholder review of Regional Climate Outlook Forums. International Workshop, 16–20 October, Pretoria, 28pp

Meinke H, Nelson R, Kokic P, Stone R, Selvaraju R, Beathgen W (2006) Actionable climate knowledge: from analysis to synthesis. Clim Res 33:101–110

Ogallo LA, Boulahya MS, Keane T (2000) Applications of seasonal to interannual climate prediction in agricultural planning and operations. Agric For Meteorol 103:159–166

Pietersen K (2006) Multiple criteria decision analysis (MCDA): A tool to support sustainable management of groundwater resources in South Africa. Water SA 32:119–128

Schneider JM, Garbrecht JD (2003) A measure of the usefulness of seasonal precipitation forecasts for agricultural applications. Trans ASAE 46(2):257–267

Stigter K (2008) Getting agrometeorology to reach all farmers. Report of a mission at the University of the Free State, Bloemfontein, South Africa: 12/1–30/4/’08. Agromet Vision, Bruchem/Bondowoso, 90pp

Thomas RJ (2008) Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change. Agric Ecosys Environ 126:36–45

Walker S (2007) Decision support tools for semi-arid Africa with user and climate inputs. SADC Land and Water Management Applied Research and Training Programme, 2nd Scientific Symposium, Gaborone, 20–22 February

Walker S, Nanja D, Gondwe P, Dimes J (2009) Mujika community climate-cropping systems modelling exercise. Poster at AgSAP Conference on Integrated Assessment of Agriculture and Sustainable Development, Egmond aan Zee, 10–12 March, pp 432–433. www.conference-AsSAP.org Session C2

III.3.4 Tactical Decision Making Based on Weather Information

III.3.4.(I) Problems and Solutions in Using of and Coping with Weather Phenomena in Need of Tactical Decision Making and Challenges Remaining for the Use of Science to Contribute to Problem Analyses and Designing Viable Solutions in This Context: Multiple Cropping

Sue Walker, Emmanuel Ofori, Nicholas Kyei-Baffour, and Kees Stigter

Walker et al. (2011) recently summarized for seasonal tactical aspects that there are many sorts of combination used in intercropping layouts or design in the field. There are also a variety of different ways of looking systematically at intercropping systems – either by height or climate zone or reason or purpose for which the crops are grown etc. If one considers that the intercrops are limited to those that are grown in the same field or land at the same time, albeit part of the growing season, then there can still be many different combinations. The crops can be either annuals or perennials (in the latter case the choice is strategical) and they can be of similar or different growth cycles and growth habits.

Then the arrangement in the field also has a range of possibilities: completely randomly mixed if seed is broadcast, or in mixed crop rows, or mixed crops in the same rows or in alternate rows of each crop, or alternate groups of rows of each crop or tree or as alternating strips of each crop, or the trees are in belts, hedges or other boundary plantings, or trees are randomly spaced in nature and the crop is grown under them (e.g. Baldy and Stigter 1997 and examples also in the literature of Sect. III.3.4.(II).

Then when compared to the sole crop there can also be a variety of densities – they can be as a pair-wise intercropping series or additive intercropping series or replacement intercropping series or a responsive intercropping series design (Connolly et al. 2001). So when one is talking about tactical decision making related to weather phenomena in intercropping, one should take care to carefully describe

S. Walker (✉)
Department of Soil, Crop and Climate Sciences, University of the Free State, Bloemfontein, South Africa
e-mail: walkers.sci@ufs.ac.za

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_40,

the plant arrangements and planting timing systems before one tries to analyze the results and especially before one tries to extrapolate the results into a different situation (Walker et al. 2011).

One of the greater tactical effects that intercropping can have in using or coping with weather phenomena is that on the soil water use and management through the growing season. To obtain an understanding of the water strategies of the intercrops, one has to investigate and understand the distribution of the roots in the soil profile (e.g. Umaya et al. 1999; Mungai et al. 2001; Oluwasemire et al. 2002; Oteng'i et al. 2007; Walker et al. 2011). See also Box III.3.1 in Sect. III.3.1.(a).

This will then help to explain the water (and nutrient) extraction patterns and water (and nutrient) use by the combined crops in the intercropping system. Mungai et al. (2001) for example explained differences in behaviour of a bean/maize intercrop under trees from a season in which incidentally another maize variety had been planted that had colonized the soil layers differently as to nutrient extraction. This was recognized in the maize growth of the following season.

In another example, the cowpea rooting system in the intercrop was well developed and more extensive even than other legumes (e.g. Oluwasemire et al. 2002; Rusinamhodzi et al. 2006). These more extensive rooting systems can then explore the soil to greater depths and volumes and so provide a means of promoting better utilization of natural resources.

This was also the case when the soil water balance was measured to a depth of 1,200 mm and a maize/bean intercrop was able to extract more water than either of the sole crops of maize or beans (Walker and Ogindo 2003). The intercrop's transpiration through the season was higher than that of either sole crop and this was attributed to the more prolific root system of the combined crops so that they were able to explore the soil profile more fully (e.g. Ogindo and Walker 2005). Rainfall distribution patterns do influence such effects of course as well, and trying to use the weather phenomena this way is just playing the higher efficiency potential cards.

Intercrops have generally been shown to give substantial improvement in water use efficiency (e.g. Morris and Garrity 1993). Oluwasemire et al. (2002) found millet using water more efficiently for grain production in its intercrops in a drier year. It showed better adaptation to moisture stress by producing similar harvest indices in sole and intercropped millet. The components used in calculating water use efficiency are the yield and the water use. The yield under intercropping needs to include that from both contributing crops and so probably is best expressed in terms of the energy value (Walker et al. 2011).

The components of the water use can be divided into the sum of the transpiration and the evaporation directly from the soil surface. However, these components are rarely separated in agronomic studies (e.g. Kinama et al. 2005). But if one is to evaluate the true productivity of the water used by the crops, one should only use the transpiration or green water as this is what is converted into biomass and yield (Walker and Ogindo 2003).

The method often used to separate the two components is that of the transpiration coefficient (e.g. Ogindo and Walker 2004). In semi-arid areas, the highest soil evaporation has been reported to be between 50 and 65% under sole crop (Ibrahim et al. 2002) or sole crop like (Kinama et al. 2005) conditions, although Walker et al. (2011) report even higher values from the literature under farmers' field conditions. Under these high evaporative demand situations, the useful water for transpiration and thus conversion to biomass is extremely low.

However, if intercropping was to be practised, there would be a higher coverage of the soil by the second crop and so it forms a sort of green or living mulch (e.g. Stigter and Baldy 1993). While it will use water for transpiration, this will also produce a crop and thus be useful water and at the same time decrease the bare soil surface evaporation. This would then also increase the water use efficiency of the combined crop (Walker and Ogindo 2003).

Together with the root system, the above soil biomass distribution is in this and other ways another tactical use made of the space in which the weather phenomena and their consequences are met and used as efficiently as possible. Because operational agrometeorology wants to solve local problems of farmers, the challenges remaining are testing new farming systems on-farm in the above suggested directions (e.g. Stigter et al. 2007). More details are also at the end of the subsequent Sect. III.3.4.(II).

In the context of adaptation and climate change resilience, we may conclude that intensification of agriculture, promoting local capacity for improved crop production, improvement in traditional farming systems and use of climate information will be the main means to increase production (Fischer et al. 2002; Stigter et al. 2005; Winarto et al. 2008). From the sections in this chapter it has become clear what multiple cropping can do here if supported by applied science. In many developing countries, provided adequate inputs and improved management strategies are applied, there is this way considerable scope for increased yields (Baldy and Stigter 1997; Fischer et al. 2002).

Adaptation strategies generally adopted and dealt with throughout Chap. III.2 that still have to be developed much wider for multiple cropping, include: adjustments to planting dates; changes in fertilization; irrigation applications; applying cultivar traits; using crop residues and cover crops; recourse to indigenous knowledge; better use of local natural resources and processes; mixed farming with adapted selection of animal species; a different utilization of marginal lands (such as for fuel crops instead of food crops); agroforestry; local specialized early warning systems; and livelihood diversification. Examples are found throughout this Chap. III.3. Research needs we therefore want to recognize in agrometeorology of multiple cropping are:

i. crops of contrasting growth habits should be selected: e.g. canopy types, crop morphology and root systems;

ii. identifying the best mixture of the crop species e.g. effect of planting densities on main and companion crops, planting densities on fertilizer use, composition on pests and diseases (Box III.3.15);

Box III.3.15

Reijntjes et al. (1992) have already long ago exemplified the generally positive effects of intercropping in terms of reducing the occurrence of insect pests, diseases and weeds as follows. Standing rice stubble can camouflage bean seedlings and protect them from bean fly. Many issues have microclimatological components related to weather and climate phenomena. Intercropping can for example interfere with the population development and survival of insect pests, because companion crops block their dispersal across the field and it may be more difficult for them to locate and remain in microhabitats which favour their development. In tactical decision making, such mechanisms can be used to change and improve existing intercropping systems as to reduce insect populations. With few exceptions, intercrops suffer less diseases than pure crops with the same overall density. Provided the pathogen/host/environment relationship is understood, like that is also aimed at in monocropping, the use of intercropping shows great possibilities for reducing disease. In many intercropping systems, only one weeding is required compared to 2–3 in sole crops, due to the shading and smothering provided. This weeding is often combined with planting another intercrop, thus reducing the time spent solely on weeding. These are again tactics using opportunities offered by environmental management.

iii. performance of improved crop varieties e.g. for drought resistance under multiple cropping systems;
iv. labor requirements (and functions) and machinery requirements (and functions) under multiple cropping systems – Farm practices that will accelerate harvesting of the first crop and the planting of the second crop;
v. develop early maturing crops;
vi. moisture conservation methods suitable for multiple cropping;
vii. identify nutrient needs under multiple cropping;
viii. productivity of companion crops under different cropping intensity and shading levels;
ix. crop rotations and fertility – Improved crop sequences involving rotation of soil exhausting crops followed by recuperative ones, shallow rooted crops followed by deep-rooted ones, legumes in rotation with non-legumes.

References

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Connolly J, Goma HC, Rahim K (2001) The information content of indicators in intercropping research. Agric Ecosyst Environ 87:191–207

Fischer G, Shah M, van Velthuizen H (2002) Climate change and agricultural vulnerability. IIASA report for the World Summit on Sustainable Development, Johannesburg. IIASA Publications Department, Vienna, Austria. http://www.iiasa.ac.at/Research/LUC/JB-Report.pdf

Ibrahim AA, Stigter CJ, Adam HS, Adeeb AM (2002) Water use efficiency of sorghum and groundnut under traditional and current irrigation in the Gezira scheme, Sudan. Irrig Sci 21:115–125

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2005) Evaporation from soils below sparse crops in contour hedgerow agroforestry in semi-arid Kenya. Agric For Meteorol 130:149–162

Morris RA, Garrity DP (1993) Resource capture and utilization in intercropping: water. Field Crops Res 34:303–317

Mungai DN, Coulson CL, Stigter CJ, Ng'ang'a JK, Mugendi DN (2001) Phenotypic nutrient uptake differences in an alley cropping system in semi-arid Machakos, Kenya. J Environ Sci 13:164–169

Ogindo HO, Walker S (2004) The determination of transpiration efficiency coefficient for common bean. Phys Chem Earth 29:1083–1089

Ogindo HO, Walker S (2005) Comparison of measured changes in seasonal soil water content by a rainfed maize-bean intercrop and component cropping systems in a semi-arid region of southern Africa. Phys Chem Earth 30:799–808

Oluwasemire KO, Stigter CJ, Owonubi JJ, Jagtap SS (2002) Seasonal water use and water yield of millet based cropping systems in the Nigerian Sudan Savanna near Kano. Agric Water Manag 56:207–227

Oteng'i SBB, Stigter CJ, Ng'ang'a JK, Liniger H-P (2007) Soil moisture and its consequences under different management in a six year old hedged agroforestry demonstration plot in semi-arid Kenya, for two successive contrasting seasons. Afr J Agric Res 2(3):89–104

Reijntjes C, Haverkort B, Waters-Bayer A (1992) Farming for the future. An Introduction to Low-External-Input and Sustainable Agriculture. Macmillan/ILEIA, London/Leusden, 250pp

Rusinamhodzi L, Murwira HK, Nyamangara, J (2006) Cotton-cowpea intercropping and its N2 fixation capacity improves yield of a subsequent maize crop under Zimbabwean rain-fed conditions. Plant Soil 287:327–336

Stigter CJ, Baldy CM (1993) Manipulation of the microclimate by intercropping: making the best of services rendered. In: Sinoquet H, Cruz P (eds) Ecophysiology of tropical intercropping, INRA, Paris/Guadeloupe, pp 29–44

Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005) Using traditional methods and indigenous technologies for coping with climate variability. Climat Change 70:255–271

Stigter K, Das H, Nguyen Van Viet (2007) On farm testing of designs of new cropping systems will serve Indonesian farmers. Available on the INSAM website under "Needs for agrometeorological solutions to farming problems"

Umaya GO, Macharia JNM, Onyango JC, Stigter CJ, Coulson CL (1999) Competition of the active roots of *Cassia siamea* Lam. and *Zea mays* L. (cv. Katumani Composite B) in an alley cropping trial in semi-arid Kenya. J Environ Sci 11:462–467

Walker S, Ogindo HO (2003) The water budget of a rainfed maize and bean intercrop. Phys Chem Earth 28:919–926

Walker S, Stigter CJ, Ofori E, Kyei-Baffour N (2011) Intercropping and its implications for soil management. In: Hatfield JL, Sauer TJ (eds) Soil management: building a stable base for agriculture. American Society of Agronomy, in press

Winarto YT, Stigter K, Anantasari E, Hidayah SN (2008) Climate Field Schools in Indonesia: coping with climate change and beyond. Low Ext Input Sust Agric (LEISA) Mag 24 (4):16–18

III.3.4.(II) Designing and Selecting Weather Related Tactical Applications for Agricultural Management and Increasing Their Efficiencies: Multiple Cropping

Emmanuel Ofori, Nicholas Kyei-Baffour, and Kees Stigter

Section III.2.4.(II) started with the observation that sustainable agricultural production needs activities which provide information aimed at helping tactical decision makers apply weather and climate information to minimize negative consequences of adverse weather and to take advantage of favorable weather conditions. Most of what was said in that section applies to multiple cropping systems also, and we will therefore deal here with particularities that need to be considered when it comes to the adoption and practice of multiple cropping where tactical decisions are concerned. Walker et al. (2011) have some recent and older literature details.

Agroforestry intercropping with its particular protective and productive associations (Huxley 1983; Reifsnyder and Darnhofer 1989; Ong and Huxley 1996; Baldy and Stigter 1997; Stigter et al. 2002, 2005, 2007) is mainly included in Chap. III.5 of this book, on non-forest trees, but to the crops grown among the trees, many of the aspects below also apply. For pros and cons see Box III.3.16. For success of tactical measures see Box III.3.17.

Box III.3.16 (Contributed by Kees Stigter)

The following review is based on Kinama et al. (2007), where also more references can be found. Tree planting is used, particularly with agroforestry systems (e.g. Garrity 1996), in water erosion reduction, often combined with other soil cover. However, major disappointments with alley cropping in the semi-arid tropics and elsewhere have already led to a greater emphasis on (i) sequential systems, such as improved fallows, which segregate trees and crops in order to remove the undesirable competitive effects of trees (Buresh and Cooper 1999) and (ii) scattered trees with root pruning (e.g. Stigter et al. 2004). Scattered trees as a strategy have been reported to generally influence

E. Ofori (✉)
Agricultural Engineering Department, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
e-mail: oforiegh@yahoo.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_41,

crops positively (e.g. Ong and Leakey 1999), but for other agroforestry systems the results are tactically not always that positive.

Mungai et al. (1996, 2001) showed that for flat land without fertilizers, yield increases due to tactical mulch incorporation in semi-arid Kenya were insufficient for cases where maize rows were strategically replaced by trees. Below a threshold rainfall, yields were even less than those in the controls (Mungai et al. 2001). Evidence of alley cropping in the semi-arid tropics of India has consistently shown a considerable reduction in crop yield, of 30–90%, when the alley width was less than 5 m (Singh et al. 1989). Subsequent research showed that competition for moisture between the roots of trees and crops was responsible for restricting crop growth in the alleys in semi-arid India and Kenya (Ong et al. 1996; Umaya et al. 1999).

Subsequent studies at Machakos showed that there was also little complementarity in the use of light and water between *L. leucocephala* and maize (e.g. Howard et al. 1995). Such findings are not confined to alley cropping systems (e.g. Rao et al. 1998; Ong et al. 2000). Root pruning, mulching and minimum tillage, as weather related tactics, improve this situation in ageing systems (Oteng'i et al. 2007a, b), while also adapted spacing may be applied. See for details Box III.3.17. Such studies confirm that the nature and extent of the interactions between trees and crops change greatly as the system matures (Ong et al. 2000; Oteng'i et al. 2007a, b). They also show that the intensity of these interactions depends on the prevailing environmental and management conditions, particularly seasonal rainfall and the tactical management of its effectivity.

Box III.3.17 (Contributed by Kees Stigter)

The following is from Oteng'i et al. (2007b), detailing tactics of root pruning, mulching and minimum tillage in an ageing agroforestry demonstration plot under the TTMI-project. Hedged agroforestry (AF) demonstration plots with maize/bean intercrops were studied at Matanya in Laikipia district, Kenya, between 1991 and 1995 inclusive, to understand crop yield behaviour due to selected soil moisture conservation methods applicable in semi-arid areas. The treatments were: *Grevillea robusta* trees root pruned, compared to unpruned, both in combination with (1) minimum tillage and mulching with 3 t/ha maize stalks harvested from the plots with additional stalks collected from the nearby farms, and (2) the locally applied method of deep tillage practised by the immigrants from wetter regions, acting as the control. Results showed that: (i) plots with root pruned *Grevillea robusta* trees that were mulched and minimum tilled had most soil moisture available in the shallower layers, during the wettest and the driest season on which this paper is based; (ii) the variation of soil moisture with distance from the *Grevillea robusta* trees showed patterns that were quite similar for plots with root pruned trees in the dry and the wet season; (iii) beans had greater seed yields and maize had more (stover) biomass and (only in the wettest season) grain in plots with pruned trees, minimum tilled and mulched, than in other AF plots.

In the wettest season this resulted in identical maize yields but lower bean seed yields compared to those in the mulched and sometimes also the local control plots without trees. In the driest season bean yields remained the same but maize biomass yields improved above the control yields for the most successful agroforestry intervention applied and (iv) competition between the 6 year old *Grevillea robusta* trees and the crops was indirectly confirmed to be stronger than in earlier experiments in the same plots. This way the agroforestry demonstration plots were very successful in showing the consequences of the ageing agroforestry system, where the soil moisture conservation measures of pruning and mulching kept their effects. Statistical analysis only weakly confirmed the positive effect of root pruning on reducing competition for soil moisture between crops and trees that was very clearly shown to exist by the physical error analysis (Oteng'i et al. 2007b).

For crop matching and crop selection, according to Bowen and Kratky (1986) successful multiple cropping will depend on detailed (strategical) planning, timely (tactical) planting of each crop, adequate fertilizer at optimal times, effective weed and pest control and efficient harvesting, the latter all being tactical decisions with weather related components. Planning in this case means selection of crop species, water availability, plant populations and spacing, labor requirements throughout the season and tillage requirement, planting time to coincide with the optimal growth periods.

Plant growth characteristics such as canopy structure, rooting depth, formative rate of main and component crops must be different to allow for compatibility as intercrop. For examples and details see also Andrews and Kassam (1976), Beets (1982), Baldy and Stigter (1997). The main crop and composite crop must have differing spatial and temporal use of environmental resources such as radiation, water and nutrients (e.g. Willey 1990). Spatial arrangements of plants, planting rates, plant architecture and maturity dates must be considered when planning intercrops (e.g. Papendick et al. 1976; Francis 1986; Baldy and Stigter 1997). General tropical crop knowledge is also necessary (e.g. Squire 1990; Norman et al. 1995; Ong and Huxley 1996).

As to spatial cropping arrangement (e.g. Baldy and Stigter 1997), possible variations are growing two or more crops at the same time with at least one crop planted in rows, growing two or more crops together in no distinct row arrangement and planting a second crop into a standing crop at a time when the standing crop is at its reproductive stage but before harvesting. Others are growing two or more crops together in strips wide enough to permit separate crop production using machines but close enough to allow crops to interact and tree/pasture/livestock systems. Plant density of component crops need to be optimized by adjusting the seeding rate below its full or sole crop rate. The seeding rate depends on the preference of the farmer as to which crop is the major crop and which ones are the intercrop and the economic importance of each crop (e.g. Willey 1985). The problem now is how much reductions will give a very good yield?

The already mentioned literature as well as Stigter and Baldy (1993) also show that planting intercrops that feature staggered maturity dates or development periods take advantage of variations in peak resource demands for nutrients, water, and sunlight. Having one crop mature before its companion crop lessens the competition between the two crops. Using information about planting dates, lengths of the growing period and days to crop maturity, crops suitable for relay cropping and other multiple cropping systems can be selected. Allowing one member of the mix to capture sunlight that would not otherwise be available to the others is another aspect. Planting should be arranged so that there is least interference and competition among crops.

Under field conditions, crop growth is dependent on the ability of the canopy to intercept incoming (solar) radiation, which is a function of the leaf area index (LAI) and canopy architecture, and convert it into new biomass. This then relates to options for the planting pattern of selected crop mixtures, such as both crops in the same row, in alternate rows, in alternate double rows, row orientation e.g. north – south and east – west. Any of the options chosen has implications for resource sharing and yield. All these factors put together form a tactical management tool for intercropping systems. Planning for fertilization should answer questions like where the source of fertilization will be. Will it be from a companion crop or from an external (inorganic) source?

As to pests and diseases control, insect pest populations are often lower when two or more crops are grown together. Some intercropping combinations have been shown to reduce the incidence or severity of pest and diseases attack compared with sole cropping (Altieri and Liebman 1986). See also Box III.3.15 of Sect. III.3.4.(I). Pesticide Action Network (PAN) in Indonesia conducts research into Alternative Pest Control (APC) in both upland and lowland crop combinations. APC involves primarily symbiotic and mutually beneficial combinations of plants e.g. cabbage/celery, carrot/leek, carrot/onion, garlic/potatoes, green bean/potatoes (Tjahjadi 1991).

For soil fertility improvement, leguminous crops sown as main crop or intercrop add to the fertility of the soil (e.g. Walker et al. 2011). In Swaziland small-scale farmers are encouraged to sow maize with groundnut in preference to the sugar bean/maize mixture as maize/groundnut mix proves to be a superior companion crop to a sugar bean/maize mix (Thwala and Ossom 2004). According to Long Li et al. (2007), maize intercropped with faba bean (*Vicia faba L.*) yielded 43 and 26% more respectively. Maize yield increase was as a result of phosphorus uptake mobilised by the acidification of the rhizosphere via faba bean root release of organic acids and other materials. The faba bean yield increase was due to differences in growth and rooting depth.

In Cantarranas, the adoption of velvet bean (*Mucuna pruriens*), which can fix up to 150 kg N/ha as well as produce 35 t of organic matter per year, has tripled maize yields to 2,500 kg ha^{-1}. Labor requirements for weeding have been cut by 75% and herbicides eliminated entirely. The focus on village extensionists was not only more efficient and less costly than using professional extensionists, it also helped to build local capacity and provide crucial leadership experience (Bunch 1987).

In summary, it is necessary to tactically ensure that competition among the different components of the system is not great enough to affect the total productivity of the system adversely (e.g. Walker et al. 2011) or is optimized under seriously limiting conditions (Oteng'i et al. 2007b). Water, nutrients and light are the factors most commonly in short supply. Water use should not be equal in competitive ability, nutrients use or need should vary.

The tactical climate element of multiple cropping is in a more complicated way than for sole cropping also about moisture availability and timing, suitable climate conditions for the growth and development of particular crops, selection of suitable crops and maximizing the use of climate and other resources that affect growth (light, water, nutrients). Others are again tactical climatic determinants of planting densities, choice of multiple cropping systems and timely advice on farming operations (weeding, spraying, pest management, harvesting and drying), again more complex versions of sole cropping requirements and determinations.

References

Altieri MA, Liebman M (1986) Insect, weed and plant disease management in multiple cropping. Francis CA (ed) Multiple cropping systems, Vol. 1. Macmillan Publishing Company, New York, pp 183–218

Andrews DJ, Kassam AH (1976) The importance of multiple cropping in increasing world food supplies. In Papendick RI, Sanchez A, Triplett GB (eds), Multiple cropping. ASA Special Publication 27. American Society of Agronomy, Madison, USA, pp 1–10

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Beets WC (1982) Multiple cropping and tropical farming systems. Westview Press, Boulder, 180pp

Bowen JF, Kratky BA (1986) Successful multiple cropping requires superior management skills. Agribusiness Worldwide. November/December:22–30

Bunch R (1987) Case study of the Guinope Integrated Development Program. Proceedings IIED Conference on Sustainable Development, International Institute for Environment and Development, London, 25pp

Buresh RJ, Cooper PJM (1999) The science and practice of short-term improved fallows. Agrofor Syst 47:1–3

Francis CA (ed) (1986) Multiple cropping systems. Macmillan, New York, 383pp

Garrity (DP) 1996 Tree-soil-crop interactions on slopes. In: Ong CK, Huxley PA (eds), Tree-Crop Interactions: a physiological approach. CAB I, Wallingford, UK, pp 299–318

Huxley PA (ed) (1983) Plant research in agroforestry. ICRAF, Nairobi, 617pp

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2007) Contour hedgerows and grass strips for erosion and runoff control in semi-arid Kenya. Arid Land Res Manag 21:1–19

Long Li, Shu-Min Li, Jian-Hao Sun, Li-Li Zhou, Xing-Guo Bao, Hong-Gang Zhang, Fu-Suo Zhang (2007) Diversity enhances agricultural productivity via rhizosphere phosphorus facilitation on phosphorus-deficient soils. PNAS 104:11192–11196 http://www.solutions-site.org/artman/publish/article_339.shtml

Mungai DN, Stigter CJ, Ng'ang'a JK, Coulson CL (1996) New approach in research education to solve problems of dryland farming in Africa. Arid Soil Res Rehab 10:169–177

Mungai DN, Stigter CJ, Coulson CL, Ng'ang'a JK, Netondo GWS, Umaya GO (2001) Understanding yields in alley cropping maize (*Zea mays* L) and *Cassia siamea* (Lam) under semi-arid conditions in Machakos, Eastern Kenya. J Environ Sci 13:291–298

Norman MJT, Pearson CJ, Searle PGE (1995) The ecology of tropical food crops, 2nd edn. Cambridge University Press, Cambridge, 415pp

Ong CK, Huxley PA (1996) Tree-crop interactions; a physiological approach. CABI, Wallingford and ICRAF, Nairobi, 386pp

Ong, CK, Leakey RBB (1999) Why tree-crop interactions in agroforestry appear at odds with tree-grass interactions in tropical savannahs. Agrofor Syst 45:109–129

Ong CK, Black CR, Marshall FM, Corlett JE (1996) Principles of resource capture and utilization of light and water. In: Ong CK, Huxley PA (eds) Tree-crop interactions: a physiological approach. CABI, Wallingford, UK, pp 73–158

Ong CK, Black CR, Wallace JS, Khan AAH, Lott JE, Jackson NA, Howard SB, Smith DM (2000) Productivity, microclimate and water use in *Grevillea robusta*-based agroforestry systems on hillslopes in semi-arid Kenya. Agric Ecosyst Environ 80:121–141

Oteng'i SBB, Stigter CJ, Ng'ang'a JK (2007a) Understanding maize/beans intercropping yield distributions from water conservation measures in a hedged agroforestry system in semi-arid Laikipia District, Kenya. J Sci Technol Educ Manag (JSTEM) 1:6–33

Oteng'i SBB, Stigter CJ, Ng'ang'a JK, Liniger H-P (2007b) Soil moisture and its consequences under different management in a six year old hedged agroforestry demonstration plot in semi-arid Kenya, for two successive contrasting seasons. Afr J Agric Res 2 (3):89–104

Papendick RI, Sanchez A, Triplett GB (eds) (1976) Multiple cropping. ASA special publication 27. American Society of Agronomy, Madison, USA, 378pp

Rao MR, Nair PKR, Ong CK (1998) Biophysical interactions in tropical agroforestry systems. Agrofor Syst 38:3–50

Reifsnyder WE, Darnhofer TO (eds) (1989) Meteorology and agroforestry. ICRAF, Nairobi, 546pp

Singh RP, Ong CK, Saharan N (1989) Above and below ground interactions in alley-cropping in semi-arid India. Agrofor Syst 9: 259–274

Squire GR (1990) The physiology of tropical crop production. CAB International, Wallingford, UK, 236pp

Stigter CJ, Baldy CM (1993) Manipulation of the microclimate by intercropping: making the best of services rendered. In: Sinoquet H, Cruz P (eds) Ecophysiology of tropical intercropping, INRA, Paris/Guadeloupe, pp 29–44

Stigter CJ, Mohammed AE, Al-amin NKN, Onyewotu LOZ, Oteng'i SBB, Kainkwa RMR (2002) Agroforestry solutions to some African wind problems. J Wind Engn Industr Aerodyn 90:1101–1114

Stigter CJ, Al-amin NKN, Oteng'i SBB, Kainkwa RMR, Onyewotu LOZ (2004) Scattered trees and wind protection under African conditions. In Ruck B, Kottmeier C, Mattheck C, Quine C, Wilhelm G (eds) Wind effects on trees. University of Karlsruhe, Germany, pp 73–80

Stigter CJ, Oteng'i SBB, Oluwasemire KO, Al-amin NKN, Kinama JM, Onyewotu LOZ (2005) Recent answers to farmland degradation illustrated by case studies from African farming systems. Ann Arid Zone 44(3):255–276

Stigter K, Das H, Nguyen Van Viet (2007) On farm testing of designs of new cropping systems will serve Indonesian farmers. Available on the INSAM website under "Needs for agrometeorological solutions to farming problems"

Thwala MG, Ossom EM (2004) Legume-maize association influences crop characteristics and yields. Proceedings of the 4th International Crop Science Congress, Brisbane, September, no pages

Tjahjadi RV (1991) Multiple cropping controls "magic bullet". PAN Indonesia. Low Ext Input Sust Agric (LEISA) Mag 7(4):17

Umaya GO, Macharia JNM, Onyango JC, Stigter CJ, Coulson CL (1999) Competition of the active roots of *Cassia siamea* Lam. and *Zea mays* L. (cv. Katumani Composite B) in an alley cropping trial in semi-arid Kenya. J Environ Sci 11:462–467

Walker S, Stigter CJ, Ofori E, Kyei-Baffour N (2011) Intercropping and its implications for soil management. In: Hatfield JL, Sauer TJ (eds) Soil management: building a stable base for agriculture. American Society of Agronomy, in press

Willey RW (1985) Evaluation and presentation of intercropping advantages. Expl Agric 2:119–133

Willey RW (1990) Resources use in intercropping systems. Agric Water Manag 17:215–231

III.3.5 Developing Risk Management Strategies

III.3.5.(α) Defining, Managing and Coping with Weather and Climate Related Risks in Agriculture: Multiple Cropping

Kees Stigter

Advantages of intercropping of crops like coffee and cocoa with shade trees were most recently exemplified in the context of climate change by Stigter and Abdoellah (2008). Their argument was that any contribution to diminishing climate change from increasing carbon sequestration on a large scale would be an example of managing a weather and climate related risk, while fighting land/forest degradation in its wake (Anim-Kwapong and Frimpong 2005). In improving on present situations, there is the need for forest reserves as public goods and the prevention of timber extraction in these reserves as well as the prevention of bushfires at certain periods of years, under village control (Ruf and Zadi 1998). Shade trees should be kept or introduced (Anim-Kwapong and Frimpong 2005). Only in such cases as the special rainforest systems in Brazil (Silberner 2008) and Costa Rica (Rainforest Alliance 2008), cocoa may be introduced.

Highly complex agroforestry systems, tree fallows followed by leguminous trees and "tree/crop shifting cultivation" have been successful to regenerate forest tree species and forest environment (Ruf and Zadi 1998). Cocoa could play a role here, in each case with local solutions. Carbon sequestration is served. Intercropping trees, including fruit trees and timber species, in line with thinning of aging cocoa trees, is a good policy. One step further and the shade trees are grown after some cash crops from newly available land, after which the cocoa is introduced (Silberner 2008). These are examples of overhauling or renewing existing systems that would benefit carbon sequestration and diminish other hazards. Cocoa would be related to reforestation now instead of the deforestation of the past (Ruf and Zadi 1998; Stigter and Abdoellah 2008).

Rare special protection from weather related risks was for example reported for multiple shelterbelts protecting millet from hot dry air in Nigeria (Onyewotu et al. 2004) and for umbrella shade trees protecting coffee from strong damaging vertical

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_42,

air movement before showers on the slopes of the Kilimanjaro (e.g. Stigter et al. 1997). Ecological functions and protective uses of multifunctional homegardens (and the same applies to other intercropping with trees, hedges and hedgerows) are listed by Altieri (1999) as (i) Ecological shade (see also Stigter 1984a); (ii) Soil improvement (see also Walker et al. 2011); (iii) Animal habitats (see also Gomes da Silva 2010); (iv) Erosion control (including drought control, see also Kinama et al. 2007); (v) Frost protection (see also Snyder and De Melo-Abreu 2005); (vi) Flood/runoff control (see also Stigter et al. 2003); (vii) Wind protection (see also Stigter et al. 2002); (viii) weed/disease control (see also Strand 2000 to understand the climate related risks).

As discussed earlier in this Chap. III.3, intercropping is also a strategy to reduce insect pests. Insects may feed preferentially on the second crop, or it may provide a more favorable habitat to increase natural enemies. Use of climatic risk assessment can help to understand the probable effects of selecting different varieties, rotation crops, and intercropping strategies. Environmental limits of the plants must be known to determine success of the primary or alternative crop in the specific environment (Strand 2000). For insect pest outbreak prevention some examples of multiple cropping systems are given in Table III.3.1 (Altieri 1994).

Table III.3.1 Selected examples of multiple cropping systems that effectively prevent insect-pest outbreaks in Latin America (Altieri 1994)

Multiple cropping System	Pest(s) regulated	Factor(s) involved	Country
Cassava intercropped with cowpeas	Whiteflies *Aleurotrachelus socialis* and *Trialeurodes variabilis*	Changes in plant vigor and increased abundance of natural enemies	Colombia
Corn intercropped with beans	Leafhoppers (*Empoasca kraemeri*), leaf beetle (*Diabrotica balteata*) and fall armyworm (*Spodoptera frugiperda*)	Increase in beneficial insects and interference with colonization	Colombia
Corn intercropped with beans	Corn leafhopper (*Dalbulus maidis*)	Interference with leafhopper movement	Nicaragua
Cucumbers intercropped with maize and broccoli	Flea beetles (*Acalymma vitata*)	unknown	Costa Rica
Corn-bean-squash	Caterpillar (*Diaphania hyalinata*)	Enhanced parasitization	Mexico
Corn-beans	Stalk borer (*Diatraea lineolata*)	unknown	Nicaragua

The factors involved here are mainly habitat factors but climatic analyses and risk assessments can support many of the traditional and newer cultural techniques (Strand 2000). An example is the use of cover crops (Box III.3.18). In-season cultural practices related to pest management are influenced by antecedent and near future weather, and these often low-technology control methods are likely to remain commonly used tools as part of an overall strategy for managing pests (Strand 2000), also in multiple cropping.

Box III.3.18

Cover crops are annual crops sown to create a favourable soil microclimate and decrease soil evaporation. They can be important as green manure for managing soils and soil fertility and in erosion control, especially in humid areas. They can provide the necessary biomass from their leaves, branches and roots to stimulate soil life and protect the soil surface (e.g. Baldy and Stigter 1997). They can be used shaded by trees as well (Reijntjes et al. 1992). They may provide weed control by allelopathy, smothering or reducing competition from the weed (Strand 2000). Some green manure and cover crops have pesticidal effects which can be used for plant protection (Reijntjes et al. 1992). Cover crops and nursery crops can provide habitat with a microenvironment different from the surroundings, and which may be more suitable for the growth and reproduction of a biocontrol agent (Strand 2000) or suitable as a trap crop.

As an example of the latter, sunnhemp is used as such in Tanzania in cabbage, coffee, citrus trees, flowers (Reijntjes et al. 1992). Sometimes, cover crops also function as a live mulch, reducing water losses from soils (Van der Heide and Hairiah 1989). Also relay fallowing is applied by sowing bush legumes among the food crops after these have established and, in the dry season, using the cut green biomass as mulch (Reijntjes et al. 1992), on or within the soil (Stigter 1984b, c). The other way around, rows of food crops are sown into a low but dense cover crop of grasses or legumes after strips of the cover crops have been removed, also leading to zero tillage (Reijntjes et al. 1992). Several very successful examples of protective cover crops in Latin America, as green manure or otherwise, were dealt with by Altieri (1999). Fighting land degradation, stabilizing hillsides, is an important issue here.

References

Altieri MA (1994) Biodiversity and pest management in agroecosystems. Haworth Press, New York, 185pp

Altieri MA (1999) Multifunctional dimensions of ecologically-based agriculture in Latin America. FAO/Netherlands Conference on the Multifunctional Character of Agriculture, Maastricht. http://csdngo.igc.org/agriculture/agr_altieri2.htm

Anim-Kwapong GJ, Frimpong EB (2005) Vulnerability of agriculture to climate change: impact of climate change on cocoa production. www.nlcap.net/fileadmin/NCAP/Countries/Ghana/COCOA_DRAFT_FINAL_REPORT.pdf

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French edition with an Epilogue. INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Gomes da Silva R (2010) Weather and climate and animal production. Chapter 12 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO

(www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]
Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2007) Contour hedgerows and grass strips for erosion and runoff control in semi-arid Kenya. Arid Land Res Manag 21:1–19
Onyewotu LOZ, Stigter CJ, Oladipo EO, Owonubi JJ (2004) Air movement and its consequences around a multiple shelterbelt system under advective conditions in semi-arid northern Nigeria. Theor Appl Climatol 79:255–262
Rainforest Alliance (2008) Sustainable agriculture. http://www.rainforest-alliance.org/agriculture.cfm?id=cocoa
Reijntjes C, Haverkort B, Waters-Bayer A (1992) Farming for the future. An Introduction to Low-External-Input and Sustainable Agriculture. Macmillan/ILEIA, London/Leusden, 250pp
Ruf F, Zadi H (1998) Cocoa: from deforestation to reforestation. Shade grown cocoa workshop. http://nationalzoo.si.edu/ConservationAndScience/MigratoryBirds/Research/Cacao/ruf.cfm
Silberner J (2008) How chocolate can save the planet. http://www.npr.org/templates/story/story.php?storyId=16354380
Snyder RL, De Melo-Abreu JP (2005) Frost protection: fundamentals, practice, and economics, Vol 1. FAO, Rome, 223pp
Stigter CJ (1984a) Traditional use of shade: a method of microclimate manipulation. Arch Meteorol Geophs Biocl B 34:203–210
Stigter CJ (1984b) Examples of mulch use in microclimate management by traditional farmers in Tanzania. Agric Ecosyst Env 11:173–176
Stigter CJ (1984c) Mulching as a traditional method of microclimate management. Arch Meteorol Geophs Biocl B 35:147–154
Stigter K, Abdoellah S (2008) Cocoa and climate change, can the lame help the blind? Invited Paper Presented at the "2008 Indonesian Cocoa Symposium", Organized by ICCRI, Jember, at Sanur. An updated version is available at the INSAM website (www.agrometeorology.org) under "Needs for agrometeorological solutions to farming problems" of 3 November
Stigter CJ, Kainkwa RMR, Mohammed AE, Onyewotu LOZ (1997). Essentials and cases of wind protection from scattered trees and shelterbelts. Opening paper In: Bonkoungou EG, Ayuk ET, Zoungrana I (eds) Les parcs agroforestiers des zones semi-arides d'Afrique de l'ouest. [Parkland Agroforestry of the semi-arid areas of West Africa.] SALWA-Network, Ouagadougou, and ICRAF, Nairobi, 232pp
Stigter CJ, Mohammed AE, Al-amin NKN, Onyewotu LOZ, Oteng'i SBB, Kainkwa RMR (2002) Agroforestry solutions to some African wind problems. J Wind Engn Industr Aerodyn 90:1101–1114
Stigter CJ, Das HP, Murthy VRK (2003) Beyond climate forecasting of flood disasters. Invited Lecture on the Opening Day of the Fifth Regional Training Course on Flood Risk Management (FRM-5). Asian Disaster Preparedness Center (Bangkok) and China Research Center on Flood and Drought Disaster Reduction (Beijing), Beijing, September. Available from ADPC (Bangkok) on CD-ROM. Also available at http://www.agrometeorology.org/fileadmin/insam/repository/ADPC2mp.pdf
Strand JF (2000) Some agrometeorological aspects of pest and disease management for the 21st century. Agric For Meteorol 103:73–82
Van der Heide J, Hairiah K (1989) The role of green manures in rainfed farming systems in the humid tropis. ILEIA Newsl 5(2):11–13
Walker S, Stigter CJ, Ofori E, Kyei-Baffour N (2011) Intercropping and its implications for soil management. In: Hatfield JL, Sauer TJ (eds) Soil management: building a stable base for agriculture. American Society of Agronomy, in press

III.3.5.(β) Developing Scales and Tools for Weather and Climate Related Risk Quantifications: Multiple Cropping

Sue Walker, Kees Stigter, and Kulasekaran Ramesh

The discussion of scales and tools development for risk quantifications must be significant for delineating areas for (coping with) weather risks rather than multiple cropping, as the former is suitable to the latter too. FORECASTERS are for example weather-pest forecast models which are tools for weather related risks in farming. Insect pest growth is thermally influenced whereas pathogens depend on minimum temperature, relative humidity, wetness duration, sunshine duration etc. (Venkatesh 2008). So again we have generic examples and indicate particularities where applicable to multiple cropping such as in pest epidemics (Patel and Shekh 2006).

Communities that are most exposed to these risks are those with limited access to technological resources and with limited development of infrastructure. Currently there are opportunities that can assist in coping effectively with agrometeorological risks and uncertainties (Meinke and Stone 2005; Stone and Meinke 2005). We have shown this throughout this book but it is also clear that for multiple cropping relatively fewer existing tools and scales have been applied.

There are generic examples galore. A climate risk screening tool has for example been developed for climate risk assessment by the World Bank (2006). To consider requirements for any level of prescribed risk for irrigation demands, as a scale a gamma probability density function (PDF) was developed by Green et al. (1999). Saha (2006) assessed the rainwater deficit of West Bengal, India, through incomplete gamma distribution analysis of water deficits accumulated over three crop growth stages. Though the total rainfall was sufficient to grow rainfed rice, due to skewed distributions the crop faces stress. More examples are in Box III.3.19 (specifically for drought) and below.

S. Walker (✉)
Department of Soil, Crop and Climate Sciences, University of the Free State, Bloemfontein, South Africa
e-mail: walkers.sci@ufs.ac.za

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_43,

Box III.3.19 (Contributed by Kulasekaran Ramesh)

Chopra (2006) delineated drought risk areas of Gujarat, India, using temporal images from the NOAA-AVHRR (8 km) based Normalized Difference Vegetation Index (NDVI) and the meteorologically based Standard Precipitation Index (SPI). They also used the Palmer Drought Severity Index (PDSI), Vegetation Condition Index (VCI), Standard Water Supply Index (SWSI), a crop moisture index and a temperature condition index for quantification of the drought. The hazard and risk assessment context of this work can be understood from ADPC/ITC/UB (2007).

Newhall Simulation Model (NSM) for quantification of agricultural drought revealed that more than 5% of the area of the Czech Republic would be faced with relatively frequent arid or xeric events, accompanied also with higher probability of less severe drought spells (Kapler et al. 2006).

Nkemdirim (2007) quantified risk as potential loss of farm income due to a higher frequency of severe droughts. Spatial distribution of drought intensity in the time window is derived via downscaling in a GIS-Statistical environment based on comparable data from the major drought events of the 1930s and 1980s. Exposure is the product of probability of a drought and the time window 2050–2080, both obtained from projections made by the Canadian climate centre coupled AOGCM.

A climate risk index based on suitability models was established combining the mean suitability level and the influence of climate change (Huaisui et al. 2006). It was found that the value of the Normalized Difference Vegetation Index (NDVI) was lower in high drought risk areas (Prathumchai et al. 2001), so it could be used for risk quantification (Elhag 2006, see also Box III.3.20). Prasad and Rana (2006) simply quantified climatic risk through analysis of maximum temperature during a particular month over 3 years, to study the impact of increased temperature on rabi crops in Himachal Pradesh, India. So indeed generic examples galore.

Box III.3.20 (Contributed by Sue Walker)

The requirements for climate risk quantification are good detailed long term climate data sets and good data bases of the crop requirements. The modifications of crop requirements under multiple cropping would also need to be available, to compare the reduced risk due to adopting a multiple cropping system in place of a mono- or sole cropping system. Then the risk can be quantified using the climate data to formulate a hazard index. The farmer's ability to cope with such a hazard or his/her failure to cope must then be quantified as the vulnerability of these farming systems to this specific hazard. Therefore in such cases a risk index should be computed using the weather forecast and the knowledge of the local farming system(s).

A risk assessment on an operational level, using daily weather data, was developed to give a warning of the risk of infection of grape vines downy mildew (Haasbroek 2006). As the vineyards are often grown together with a pasture or cover crop, or adjacent to fruit tree orchards, these can also be considered to be multiple cropping systems. The downy mildew infections are triggered by different weather conditions. Therefore, each day the automatic weather station data are downloaded and run through a model, to predict the risk of infection that has occurred over the last 2 weeks. This information is then sent via e-mail or mobile phone text message service to the growers each day (Walker and Haasbroek 2007).

This type of risk quantification and those of Box III.3.19 can also be performed across a whole country or an extended part of a country, so as to be also of use to decision makers at the highest national government level. Here are such examples from Africa:

- The central Rift Valley of Ethiopia is a major agricultural area, yet suffers from frequent drought. Walker and Mamo (2007) developed a tool that simply qualifies the rainfall probabilities across the central Rift Valley. This information is integrated with the long term simulation of sorghum production at different planting dates, with varieties with different lengths of the growing season and at different fertility levels (Diga 2005). The tool works in such a way that the 3 months seasonal rainfall predictions from at least three providers are used as input and compared with the long term rainfall probabilities and simulated yields, so as to be able to make recommendations. These recommendations include when to plant, which varieties (as to length of the growing season) to plant or whether to refrain from planting until sufficient rainfall or a more favorable forecast is recurred (Diga 2005; Walker and Mamo 2007).
- As NDVI is an index of the vegetative cover, it represents an integrated index of multiple cropping systems for combined cropping and pastoral systems. In the Butana area east of the Blue Nile river, satellite data were used together with aerial maps and community groups to quantify the effect of desert encroachment (Elhag 2006). Then the long term rainfall data of the region were compared with the land cover trend from the portion of the effect attributed to human influence (Elhag and Walker 2009). These studies were consolidated into a simple discussion support tool (TASHUR) to be used at a national level to assess the effects of changing land use and shifts between cropping and pastoral systems (Elhag and Walker 2007).

Singh et al. (1990) developed an index that has been evolved for identifying a year as hydrological flood/drought year in different parts of India, based on the total seasonal rainfall of June through September as well as its timing. After giving a margin of 25% to the mean index value for normal years, frequencies of flood/drought years have been calculated on that scale. Bringing the simple probabilistic seasonal climate forecasts scale (we have come across before, see for example WMO 2010) into management decisions can reduce the vulnerability of agriculture to floods and droughts caused by ENSO (El Niño Southern Oscillation) phenomena (Sivakumar 2006), provided that a series of participatory precautions are taken and livelihood issues are understood (Stigter 2004). See also Tsubo and Walker (2007) and Chap. IV.12. For multiple cropping just again complexity increases.

If one considers the farming system holistically, then it is important to know what the objectives of the farmer are so that one can classify them into risk averse or risk tolerant. If the household or family is totally dependent on the crop for its food security, then usually they will make decisions with low risks, also when they do not produce the maximum yields. Many times, the use of multiple cropping is to help spread the risks of a variable climate. This means that when a wide variety of crops are grown, the risk of complete crop failure is a lot smaller. The unfavorable climate or hazard will usually not occur during the critical physiological phases of all the crops. Thus multiple cropping spreads the risk and allows the farmer to produce a crop from at least one of a group of crops cultivated that season. However, very little detailed information is available concerning scientific analysis of such systems. One could use a whole farm type model where the loss is calculated according to production or farm income.

In order for the risks of specific crops or combinations of crops in multiple cropping systems to be quantified, one needs to locate the available crop-climate relationships information in such a way as to develop boundaries within which these crops can grow optimally. These crop specific climate windows can then be used as yardsticks against which to compare the climate of a region, to assess the climatic risks involved if the crops were to be cultivated.

The types of climate risk quantification tools, scales and indexes exemplified above could then be applied to various agricultural cropping systems. If one were to consider multiple cropping systems, then one would need to use research results for each of the crop components, together with a full range of weather parameters. All specific weather parameters that were critical for the particular crop would be included. Thus, the different crops would be differently sensitive to weather parameters and at different critical levels.

Crop-climate matching exercises can themselves be done using various models or indices. One such simple method assigns a suitability ecological class to each of the areas within a region (Ehlers 1988). Then a whole range of suitable crops (but also marginal crops) can be listed for that area. Another tool is the FAO Ecocrop2 model which uses the long term climate together with the crop requirements, to select suitable crops for a specific area (FAO 2004; Zuma-Netshiukhwi and Walker 2007, 2009).

If the temperatures (maximum and minimum) and rainfall probability density functions have been calculated, the risk involved in the various crop choices can be determined. The advantage of these systems is that one can develop good combinations of legumes and cereals for use in multiple cropping systems. As Ecocrop2 also has a range of herbs and spices and tree crops (fruits and nuts), one can easily develop optimal combinations for new multiple cropping systems that are suitable for the particular climatic zone.

References

ADPC/ITC/UB (2007) Guidelines for a joint research. Deliverable for Activity 5 of the CASITA II project. Asian Disaster Preparedness Centre, Bangkok. http://www.adpc.net/v2007/Programs/UDRM/PROGRAMS%20&%20PROJECTS/CASITA/Activities/Activity%205%20Guideline%20Joint%20Research%20Finall.pdf

Chopra P (2006) Drought risk assessment using remote sensing and GIS: a case study of Gujarat. Unpublished MSc thesis submitted to the International Institute for Geoinformation Science and Earth Observations (ITC), Delft, The Netherlands, 400pp

Diga GM (2005) Using seasonal climate outlook to advise on sorghum production in the Central Rift Valley of Ethiopia. Unpublished PhD thesis, University of the Free State, Bloemfontein, South Arica, 173pp

Ehlers JH (1988) Ekologiese beplanning van gewasse. [Ecological planning for crops] Dept. van Landbou Tegniese Dienste, Transvaal streek, South Africa, no pages

Elhag MM (2006) Causes and Impact of desertification in Butana area of Sudan. Unpublished PhD thesis, University of the Free State, Bloemfontein, South Africa, 171pp

Elhag M, Walker S (2007) TASHUR – An integration of indices to assess desertification. Presented at Farming Systems Design 2007: International Symposium on Methodologies for Integrated Analysis of Farm Production Systems, Catania, 10–12 September. http://www.agrometeorology.org/files-folder/repository/ElhagWalker07Desertification Indices FarmSystemItaly.pdf

Elhag M, Walker S (2009) Impact of climate variability on vegetative cover in the Butana area of Sudan. Afr J Ecol 47:11–16

FAO (2004) Ecocrop1&2. FAO Land and Water Digital Media Series, CDROM. Rome. http://ecocrop.fao.org/ecocrop/srv/en/home

Green SR, Clothier BE, Mills TM, Millar A (1999) Risk assessment of the irrigation requirements of field crops in a maritime climate. J Crop Prod 2:353–377

Haasbroek PD (2006) Verfyning en Verbetering van 'n Donsige Skimmel Waarskuwingsmodel vir die Wes-Kaap. [Refinement and improvement of a Downy Mildew Early Warning Model for the western Cape] Unpublished MSc thesis, University of the Free State, Bloemfontein, South Africa, 140pp

Huaisui Qian, Ren Yuyu, Li Mingxia (2006) Changes of crop climate risk degree: a case study on cotton in Henan Province. J Geogr Sci 16:355–362

Kapler P, Trnka M, Semerádová D, Dubrovský M, Žalud Z, Svoboda M, Eitzinger J, Hösch J (2006) Newhall model for assessment of agricultural drought event probability under present and changed climatic conditions. Geophys Res Abstr 8:10340

Meinke H, Stone RC (2005) Seasonal and inter-annual climate forecasting: the new tool for increasing preparedness to climate variability and change in agricultural planning operations. Clim Change 70: 221–253

Nkemdirim L (2007) Risk assessment in new drought environments. Geophys Res Abstr 9:00118

Patel HR, Shekh AM (2006) Pest epidemics and role of meteorological services: an overview. J Agrometeorol 8:104–113

Prasad R, Rana R (2006) A study of maximum temperature during March 2004 and its impact on rabi crops in Himachal Pradesh. J Agrometeorol 8:91–99

Prathumchai K, Honda K, Nualchawee K (2001) Drought risk evaluation using remote sensing and GIS. A case study of Lop Puri province. Paper Presented at the 22nd Asian Conference on Remote Sensing, Singapore, 5–9 November. http://www.geoinfo.ait.ac.th/publications/ACRS2001_Prathumchai_K.pdf

Saha A (2006) Characterization of rainwater deficit at growth stages of rainfed kharif rice for timely and delayed transplanting in the new alluvial zone of West Bengal. J Agrometeorol 8:65–71

Singh N, Krishnakumar K, Kripalani RH (1990) A rainfall index for hydrological floods/droughts over India. Musam 41:469–474

Sivakumar MVK (2006) Climate prediction and agriculture: current status and future challenges. Clim Res 33:3–17

Stigter CJ (2004) The establishment of needs for climate forecasts and other agromet information for agriculture by local, national and regional decision-makers and users communities. In: Applications of Climate Forecasts for Agriculture. Proceedings of the RA I (Africa) Expert Group Meeting, Banjul, December 2002. AGM-7/WCAC-1, WMO/TD-No. 1223, WMO, Geneva, pp 73–86

Stone RC, Meinke H (2005) Operational seasonal forecasting of crop performance. Phil Trans R Soc B 360:2109–2124

Tsubo M, Walker S (2007) An assessment of productivity of maize grown under water harvesting system in a semi-arid region with special reference to ENSO. J Arid Environ 71:299–311

Venkatesh H (2008) Weather and pests. All India coordinated research project on agrometeorology – Bijapur. CRIDA, Hyderabad. pp 1–31

Walker S, Haasbroek PD (2007) Use of a mathematical model with hourly weather data for early warning of downy mildew in vineyards. Farming Systems Design 2007: International Symposium on Methodologies for Integrated Analysis of Farm Production Systems, Catania, 10–12 September. http://www.agrometeorology.org/files-folder/repository/WalkerHaasbroek07DownyMildewFarmSystemItaly.pdf

Walker S, Mamo DG (2007) Decision support tool for sorghum production under variable rainfall in the Central Rift Valley. Farming Systems Design 2007: International Symposium on Methodologies for Integrated Analysis of Farm Production Systems, Catania, 10–12 September. http://www.agrometeorology.org/files-folder/repository/WalkerMamo07SorghumCRV-FarmSystemsItaly.pdf

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by C.J. Stigter. WMO, Geneva, in press

World Bank (2006) Managing climate risk. Integrating adaptation into World Bank Group operations. World Bank Group/GEF Programme, Washington. http://siteresources.worldbank.org/GLOBALENVIRONMENTFACILITYGEFOPERATIONS/Resources/Publications-Presentations/GEFAdaptationAug06.pdf

Zuma-Netshiukhwi GNC, Walker S (2007) Crop-climate matching for Modder/Riet catchment. Poster Presented at Crops-Soil-Horticulture Combined Conference, Badplaas, January

Zuma-Netshiukhwi GNC, Walker S (2009) Crop-climate matching for south-western Free State. Africa Crop Science Society Conference: Science and Technology supporting Food Security in Africa, Cape Town, 28 September–1 October, abstract only

III.3.5.(γ) Improving Weather and Climate Related Risk Assessments in Agricultural Production: Multiple Cropping

Kulasekaran Ramesh, Kees Stigter, and Sue Walker

Climate and weather related risk assessments are deep looks at what can go wrong in farming due to the (changing) environment. After such an analysis it has to be decided with what accessible ways and means to minimize the potential threats of that (changing) environment to crop production. Garcia et al. in Andre et al. (2010) stated that agricultural planning – strategic and tactical – needs to appreciate climate-related and other risks to attain the producer's goals and to spell out the sort of information that farmers need to aid their planning: climate, technical/managerial, market. A key aspect needed in linking climate and weather risk to agricultural planning is to appreciate the overall management system in question from the decision-makers viewpoint (Andre et al. 2010). It is clear that in multiple cropping this has its own specific set of aspects to target. We are again forced to deal with the subject in a generic way and to indicate where multiple cropping aspects need particular attention. See particularly for models and decision making also Box III.3.21.

Box III.3.21

Already close to 20 years ago Katz and Brown (1992) stated that the frequency of occurrence of extreme weather events is better correlated with changes in the variability, as opposed to the mean values, of climatic variables. In coupling meteorological information to crop-climate models it must be remembered that crop simulation models reflect a mixture of linear and non-linear responses and, in the broadest sense, transpose a distribution of weather sequences into a distribution of total dry matter and, in the case of crop plants, harvestable yield.

Most models are specific to the major ecosystem in which they have been developed and have an important empirical base. This includes many of the crop models that have been developed to predict grain yield, or evaluate man-

K. Ramesh (✉)
IHBT(CSIR), Palampur, India; IISS(ICAR), Bhopal, India
e-mail: ramechek@yahoo.co.in

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_44,

agement strategies such as different sowing dates, and how the efficiency of water use and of use of nitrogen and other fertilizers may be manipulated (Andre et al. 2010). Models for multiple cropping conditions are even much rarer. Semenov and Porter (1995) and Andre et al. (2010) suggested that researchers working on assessment of the effects of climate on agricultural production and appraisal of associated risks to the food supply need to bear such matters in mind.

Water budgeting facilitates the determination of length of the crop growing season, identification of suitable crops and cropping systems, forecasting of yield and monitoring droughts (Kumar 1992). By using climatic forecasts of expected seasonal rainfall, it is possible to determine if the season would be a low, normal or high rainfall season (e.g. Russell 1991), thus enabling assessment of the cropping potential of the period or area and the risks of yield variability.

We have argued in this book and elsewhere (WMO 2010) that we have not come much further in agrometeorological services. However, when properly used, such information could enable tactical intra-seasonal crop management planning/decision-making, and increase the capacity to adapt to climatic variability by reducing vulnerability to climatic risks (Amissah-Arthur 2005). This must particularly be developed for multiple cropping systems.

Risk assessment is a methodology to determine the nature and extent of risks by analyzing potential threats and evaluating existing conditions of vulnerability. Proper assessment of a particular disaster risk requires a detailed historical analysis of past events, estimates of recurrence frequencies, numerical hazard modeling, zonation of the potential hazard, and, finally, preparedness and planning for mitigation, public safety, protection of property, effective warning procedures and effective warning dissemination (Pararas-Carayannis 2003). Box III.3.22 deals with this for drought. Again for multiple cropping systems, preparedness and planning actions will demand specific approaches.

Box III.3.22

For example drought impact assessments begin by identifying direct consequences of the drought, such as reduced crop yields, livestock losses, and reservoir depletion. These direct outcomes can then be traced to secondary consequences (often social effects), such as the forced sale of household assets or land, dislocation, or physical and emotional stress (Ribot et al. 1996). This initial assessment identifies drought impacts but does not identify the underlying reasons for these impacts (Knutson et al. 1998).

The Zimbabwe Meteorological Services is collaborating with Australian scientists with a view to adopt the Strategic Drought Management System of the Grassland and Rangeland Assessment by Spatial Simulation as decision support tools. The Grass Production Model (GRASP) uses real time data (rainfall, temperatures, humidity and evaporation), historical climate data and data about soils, pasture type, stocking rate and tree cover. It produces information about soil moisture and biomass utilization which can be used to produce land degradation alerts and feed deficit alerts. The GRASP model, coupled with rainfall decile analyses and greenness maps from NOAA satellite data, provides risk information to extension, policy and decision makers (De Jager et al. 1998; Chikoore and Unganai 2001).

An operational agricultural drought risk assessment model for Nebraska, USA, was developed by Wu and Wilhite (2004) and an operational system for farmers in Florida is also in existence (Jagtap et al. 2002).

In Sect. III.2.5.(γ) we indicated that irrespective of their resource endowments, farmers share some common possibilities to address variability and changes in environmental conditions and associated risks (Rotter and Van Keulen 1997): (a) choice of crop species, crop cultivars and rotations; (b) choice of location within the farm for specific crops; (c) choice of planting dates and intensity of cultivation; (d) frequency and timing of fieldwork. We have learned from other parts of this Chapter that this also applies to multiple cropping systems. Rosenzweig (1982) and Parry and Carter (1988) already showed how difficult it is to assess climate risk for agricultural areas and crops at local scale. Generally, in actual assessments, climatic risk was largely estimated and great effort was put in large-scale studies, for example in the Mediterranean (Motroni et al. 2002), Australia (Potgieter et al. 2005) and South Africa (De Jager et al. 1998).

Mahul (2005) assessed agricultural risk through risk identification and a probabilistic agricultural risk model shown in Fig. III.3.1. These risk assessments are not predictions that can be assessed with hindsight as “right” or “wrong”. They simply provide the chances, based on history, of a particular result occurring (Hacker et al. 2006). However, when available prior to the season, they can be used in planning for the upcoming season against the odds or probability coming from the global climate models’ predictions.

Climate risk assessment should initiate the process of adaptation. To locate the temporal and sectoral climate risks, impact modeling was initiated. It has to continue to support the development process, providing projections of the hazards at a local user level. The hazard scenarios of a defined area developed through modeling may then be overlaid on the livelihood calendar, considering the different levels of vulnerability of various groups. Scientific information can now be validated by the local community and a participatory climate risk assessment together with adaptation action plans can be prepared. In the process best practices could be replicated as proven means of adaptation to climate (variability and) change (Islam 2008).

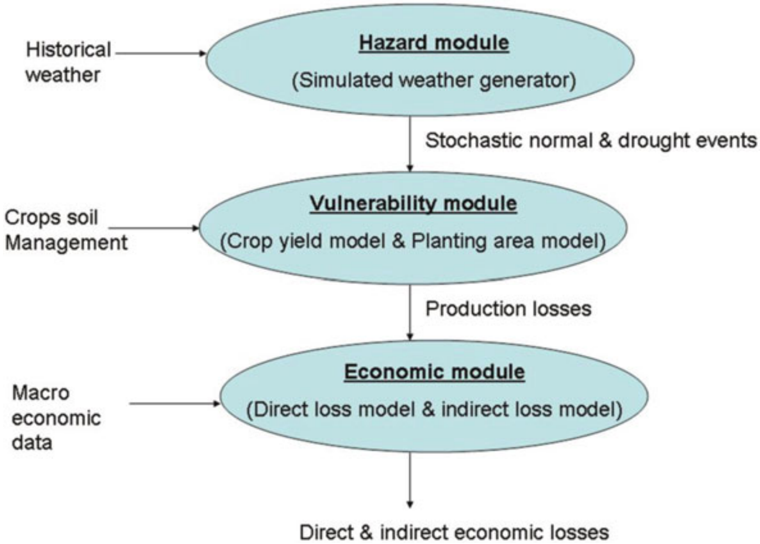


Fig. III.3.1 Probabilistic agricultural risk model (from Mahul 2005)

Semenov and Porter (1995) suggested to use a stochastic weather generator instead of historical data in conjunction with a crop simulation model. A stochastic generator allows temporal extrapolation of observed weather data for agricultural risk assessment and provides an expanded spatial source of weather data by interpolation between the point-based parameters used to define the weather generator (Hutchinson 1991). Portfolio analysis appeared to be a suitable instrument for analysing effects of climate change at farm level in The Netherlands.

A typical Dutch arable farm with potatoes, sugar beet and winter wheat on poor sandy soils was analysed in accordance with sets of historic and projected weather conditions It appeared that the impact of changed risk prospects cannot be assessed without considering the potential impact on the whole portfolio of farm-specific risk prospects (Van Asseldonk and Langeveld 2007). A portfolio risk assessment in Bangladesh considered risks in terms of current and future hazards and the sensitivity and exposure of human systems. The analysis highlighted opportunities for integrating disaster risk reduction and climate change adaptation within the context of programme activities or design, drawing on previous studies and government reports (Tanner et al. 2007).

Brazil started an official program of agricultural zoning in 1996, to define planting calendars for rice, beans, corn, soybean, wheat, sorghum, cotton, coffee, and fruits, based on simulation of a cumulative water balance (Zullo et al. 2006). These calendars were calculated to provide plants with adequate water supply during the reproductive stage and no excess during the harvest period in 80% of all simulated cases. A cumulative water balance model, BIPZON (Forest 1984), was used to calculate the Water Requirement Satisfaction Index (WRSI) based on historical rainfall data, potential evapotranspiration, length of growth stages, and soil water holding capacity. The agricultural zoning is based on the integration of crop growth models, climate and soil databases, decision analysis techniques, and geoprocessing tools (Zullo et al. 2006).

Assessment of flood risks is a complex problem that can only be solved through interdisciplinary research. A two-step approach has been adopted. First it was needed to characterize the flood hazard using a selected set of indicator maps, like the spatial distribution of flow velocity, water height, speed of propagation, duration, etc. The second step was to estimate how the flood hazard indicators interfere with human activities in the flooded area (Alkema 2003).

For the characterisation of potential floods a two-dimensional finite element propagation model Delft-FLS (Stelling et al. 1998) was used. To assess flood risk, additional information is needed on the tolerance to floods of the various land use units in the inundated territory and their value. A preliminary flood risk model was made, using GIS to integrate the flood hazard indicator maps, the tolerance to flood information and data on the value of property into two complementary impact assessments (Alkema 2003).

It follows from the above that a variety of approaches has been used for risk assessment and there is not a single standard method. However, what to apply largely depends on the specific situation and the circumstances of the agricultural systems as well as the requirements for the assessment. In general, one should have a good climate database of the area and then use this together with the local information about the current farming systems. Because of a scarcity of the latter information for multiple cropping systems, we have a long way to go in the agrometeorology of risk assessments for such systems, although in principle the combination of crops is just a complication but does not make the approaches principally different.

References

Alkema D (2003) Flood risk assessment for EIA; an example of a motorway near Trento, Italy. Studi Trentini di Scienze Naturali – Acta Geol 78:147–153. http://www.itc.nl/library/Papers_2003/peer_jrnl/alkema_flood.pdf

Amissah-Arthur A (2005) Value of climate forecasts for adjusting farming strategies in sub-Saharan Africa. GeoJ 62:181–189

Andre RGB, Garcia A, De Melo-Abreu JP, Nieto R, Prasad PVV, White D (2010) Climate and weather risk assessment for agricultural planning. Chapter 7 (Coordinated and edited by Garcia A) In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Chikoore H, Unganai L (2001) Integrating climate forecast information in agricultural management: a perspective from Southern Africa. In: Open Meeting of the Global Environmental Change Research Community, Rio de Janeiro, 6–8 October, Brazil, no pages

De Jager JM, Potgieter AB, Van den Berg WJ (1998) Framework for forecasting the extent and severity of drought in maize in the Free State Province of South Africa. Agric Syst 57:351–365

Forest F (1984) Simulation du bilan hydrique des cultures pluviales. Presentation et utilisation du logiciel BIP. [Simulation of the water balance of rainfed crops. Presentation and use of the computer programme BIP.] IRAT/CIRAD, Montpellier, France, 63pp

Hacker RB, Alemseged Y, Carberry PM, Browne RH, Smith WJ (2006) Betting on rain, managing seasonal risk in western NSW. Department of Primary Industries, State of New South Wales, Australia. www.dpi.nsw.gov.au/publications?a=63667

Hutchinson MF (1991) Climatic analyses in data sparse regions. In: Muchow RC, Bellamy JA (eds) Climatic risk in crop production: models and management for the semiarid tropics and subtropics. CAB International, Wallingford, pp 55–73

Islam MA (2008) Climate change and development risk: Local perspective. The Daily Star, March 15, Dhaka, Bangladesh. http://www.thedailystar.net/story.php?nid=27722

Jagtap SS, Jones JW, Hildebrand P, Letsonc D, O'Briend JJ, Podestá G, Zierden D, Zazueta F (2002) Responding to stakeholder's demands for climate information: from research to applications in Florida. Agric Syst 74:415–430

Katz RW, Brown BG (1992) Extreme events in a changing climate: variability is more important than averages. Clim Change 21:289–302

Knutson C, Hayes M, Phillips T (1998) How to reduce drought risk. A guide prepared by the preparedness and mitigation working group of the Western Drought Coordination Council. National Drought Mitigation Center, Lincoln, Nebraska. http://drought.unl.edu/plan//risk.pdf

Kumar VP (1992) Moisture budgeting in dry land crop production. Chapter 4 In: Somani LL (ed) Dry land agriculture: state of art of research in India. Scientific Publishers, Jodhpur, India, 671pp

Mahul O (2005) Agricultural risk financing in low and middle income countries: Challenges and opportunities. Global Conference on Insurance and Reinsurance for Natural Catastrophe Risks, Istanbul, December 8–9. http://www.tsrsb.org.tr/NR/rdonlyres/928EF283-422D-4514-B579 C0E83FDD7E77/1187/Mahul_AgRiskFinancingLowIncome.ppt

Motroni A, Duce P, Spano D, Canu S (2002) Estimation of climatic risk for agriculture in a Mediterranean region. Proceedings of the 15th Conference on Biometeorology and Aerobiology, Kansas City, 27 October–1 November, pp 308–309

Pararas-Carayannis G (2003) Climate change, natural and man made disasters- assessment of risks, preparedness and mitigation. 30th Pacem in Maribus (Peace in the Oceans). International Ocean Institute, Kiev, Ukraine, October 26–30. http://www.drgeorgepc.com/ClimateChange.html

Parry ML, Carter TR (1988) The assessment of effects of climatic variations on agriculture: aims, methods and summary of results. In: Parry ML, Carter TR, Konijn NT (eds) The impact of climatic variations on agriculture, Vol. 1. Reidel, Dordrecht, Netherlands, pp 11–95

Potgieter AB, Hammer GL, Doherty A, De Voil P (2005) A simple regional-scale model for forecasting sorghum yield across North-Eastern Australia. Agric For Meteorol 132:143–153

Ribot JC, Najam A, Watson G (1996) Climate variation, vulnerability and sustainable development in the semi-arid tropics. Introduction to: Ribot JC, Magalhães AR, Panagides SS (eds) Climate variability, climate change and social vulnerability in the semi-arid tropics. University of Cambridge, New York, no pages

Rosenzweig NJ (1982) Potential CO_2-induced climatic effects on the North American wheat producing regions. Clim Change 7:367–389

Rotter R, Van Keulen H (1997) Variations in yield response to fertilizer application in the tropics: II. Risks and opportunities for smallholders cultivating maize on Kenya's arable land. Agric Syst 53: 69–95

Russell JS (1991) Prospects for incorporation of long-term weather forecasting into crop decision support systems. In: Muchow RC, Bellamy JA (eds) Climatic risk in crop production: models and management for the semi-arid tropics and subtropics. CABI, Wallingford, pp 467–487

Semenov MA, Porter JR (1995) Climatic variability and the modelling of crop yields. Agric For Meteorol 73:265–283

Stelling GS, Kernkamp HWJ, Laguzzi MM (1998) Delft Flooding System, a powerful tool for inundation assessment based upon a positive flow simulation. In: Babovic V, Larsen I (eds) Hydro-informatics. Balkema, Rotterdam, pp 449–456

Tanner TM, Hassan A, Islam KMN, Conway D, Mechler R, Ahmed AU, Alam M (2007) ORCHID: piloting climate risk screening in DFID Bangladesh. Summary research report. Institute of Development Studies, University of Sussex, UK. http://www.iiasa.ac.at/Research/RAV/Presentations/orchid_summary_research_report_2007.pdf

Van Asseldonk MAPM, Langeveld JWA (2007) Coping with climate change in agriculture: A portfolio analysis. Paper Presented at the 101st EAAE Seminar "Management of Climate Risks in Agriculture", Berlin, July 5–6. https://wisola.agrar.hu-berlin.de/wisola/fachgebiete/betriebslehre/eaae/fpdfs/asseldonk

Wu H, Wilhite DA (2004) An operational agricultural drought risk assessment model for Nebraska, USA Natur Haz 33:1–21

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by C.J. Stigter. WMO, Geneva, in print

Zullo Jr. J, Pinto HS, Assad ED (2006) Impact assessment study of climate change on agricultural zoning. Meteorol Appl 13:69–80

III.3.5.(δ) Designing and Communicating Improvements in Farm Applications of Risk Information Products: Multiple Cropping

Kees Stigter

We started Sect. III.2.5.(δ) with the statement that risk information products are building stones of agrometeorological services (also Stigter 2005; Rathore and Stigter 2007). An example from Nigeria for intercropping was shown by Stigter et al. (2005). This picture for multiple cropping was drawn for Africa as early as 15 years ago (Oluwasemire et al. 1995) but for China only recently (Stigter et al. 2008).

Based on such work, Olufayo et al. (1998) concluded that third world scientists should concentrate on problems that have jointly been identified with local farmers. They recommended that participatory on-farm validation of new approaches and technologies that take traditional and more recent local expertise into account should particularly be undertaken more frequently. Where researchers have succeeded in this, results have been much more easily absorbed and adapted by the farmer communities and government organizations concerned (Olufayo et al. 1998; Onyewotu et al. 2003).

A livelihood approach is needed (e.g. Winarto et al. 2008). But there are many constraints (Jagtap and Chan 2000; Stigter 2007). Box III.3.23 gives an approach developed by Murthy (2008a) that will be excellently applicable to the complicated situation of multiple cropping farming systems. It is one of the few examples of new developments in extension agrometeorology that are worth mentioning. It basically is an example of a Climate Field School (Winarto et al. 2008) just like also used in the Chinese multiple cropping example referred to above (Stigter et al. 2008).

There are also other risks. Within reasonable limits, farmers' response to rapid population growth can lead to more intensive sustainable land management practices (Boffa 1999). This is in line with results from Tiffen et al. (1994) in Machakos, Kenya.

However, the opposite has been reported on vulnerable land a lot for fragile agro-ecosystems under population pressure (e.g. Jagtap and Chan 2000) unless

K. Stigter (✉)
Agromet Vision, Bruchem, Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_45,

biodiversity and ecological and other multifunctionality are kept (Altieri 1999). Boffa (1999) deals with supposed higher soil fertility in the presence of potentially risky larger trees and the suggested mechanisms include soil microbial activity, atmospheric inputs, nitrogen fixation, dung deposition, pre-existing soil fertility and soil management practices.

One of the conclusions is that more specific information is needed on the dynamics of soil fertility with increasing tree size in relation to the performance of associated crops. Recommendations are needed on size/age and related conditions of tree stands from which increased nutrient availability could potentially generate enhanced crop yields (Boffa 1999). However, in the areas concerned agroforestry research is very limited.

It is also stated that so far, the depressive effect of tree-crop competition and its spatial patterns have not been clearly measured and demonstrated in agroforestry parklands. However, it is well known that the difference in productivity between tree covered and treeless sites is substantially reduced when fertilizer is applied and/or abundant water is available (Boffa 1999). Appropriate participatory research should be designed before anything can be communicated on recommended designs in these matters (also Onyewotu et al. 2003).

Box III.3.23

Field Exercise on "Murthy's Daily Weather-Agriculture Connection" [Shortened edited version. Full original version in Murthy (2008a). See also Murthy and Stigter (2006) and Murthy (2008b).]

Material required: (a) Previous 30 days newspaper cuttings with (risk) information on weather; (b) A traditional almanac locally followed by the farmers; (c) Relevant information on effect of weather/climate on crops, agricultural operations and animals (Preparation of this information specific to the village/s takes lots of time and you need to translate the information from English language into local language). Please prepare at least 20 A4 size pages of information.

Procedure: (a) Arrange for a meeting of 50–100 farmers under a shade of a tree. (b) Ask two of the farmers to paste the 30 days weather clippings on a white sheet. (c) Ask two separate farmers to carefully observe the 30 days trends in weather as was noticed in the news paper. (d) Ask two more farmers to read and explain the weather predicted in the locally followed almanac. (e) Ask two more farmers to explain on what effects of weather they observed on crops, agricultural operations and animals in the last 30 days. (f) By carefully listening to all these farmers and after having the grip of the situation explain the scientific base of the cause and effects of weather.

Results: The measures to be taken by the farmers may be given from the following:

- Relevant (risk) information on effect of weather/climate on crops, agricultural operations and animals.
- Murthy's "Comparison Concept" taking into account the weather/climate forecast issued in real-time basis, and its derived parameters, as the basis for forewarning. These real time (risk) forecasts and derived parameters are compared with the scenarios of past seasons or years and a suitable set of common similarities on levels of pests and disease incidence and crop performance are arrived. This information helps to produce future (risk) scenarios of occurrence of pests and diseases, crop yield etc., in addition to determining the levels of incidence of pests and diseases and projected crop yield in the ongoing season.

Feedback and analysis: Hand over the pamphlets prepared, containing the effects of weather on the crops grown in the village and coping options to two farmers. Get the feed back of the farmers at regular intervals of 10 days in a highly systematic way.

References

Altieri MA (1999) Multifunctional dimensions of ecologically-based agriculture in Latin America. FAO/Netherlands Conference on the Multifunctional Character of Agriculture, Maastricht. http://csdngo.igc.org/agriculture/agr_altieri2.htm

Boffa J-M (1999) Agroforestry parklands in Sub-Saharan Africa. FAO Conservation Guide 34, Rome, 230pp

Jagtap SS, Chan AK (2000) Agrometeorological aspects of agriculture in the sub-humid and humid zones of Africa and Asia. Agric For Meteorol 103:59–72

Murthy VRK (2008a) Field exercise on "Murthy's daily weather-agriculture". Asia, India, submitted on 6/4/'08. In Stigter CJ, "Hands on" training for response farming. Reactions to calls for information collection and exchange. Version 1, June 2008. Available at the INSAM website (www.agrometeorology.org) from the homepage

Murthy VRK (2008b) Report on the project entitled "WMO-ANGRAU-DST sponsored Roving Seminars on Weather, Climate and Farmers", available on the INSAM website (www.agrometeorology.org) under "Needs for agrometeorological solutions to farmer problems"

Murthy VRK, Stigter CJ (2006) Operational agrometeorological services for extension needs and the supportive role of agricultural research. In: Strengthening Operational Agrometeorological Services at the National Level, Manila, Philippines. AGM-9, WMO/TD 1277, Geneva, pp 199–208

Olufayo AA, Stigter CJ, Baldy C (1998) On needs and deeds in agrometeorology in tropical Africa. Agric For Meteorol 92:227–240

Oluwasemire KO, Owonubi JJ, Oladipo EO, Jagtap SS, Stigter CJ (1995) Microclimate improvement and soil protection of intercropping with leguminous cover crops. In: Stigter CJ, Wang'ati FJ, Ng'ang'a JK, Mungai DN (eds) The TTMI-project and the "Picnic"-model: an internal evaluation of approaches and results and of prospects for TTMI-Units, Wageningen Agricultural University, the Netherlands, pp 212–223

Onyewotu LOZ, Stigter CJ, Abdullahi AM, Ariyo JA, Oladipo EO, Owonubi JJ (2003) Reclamation of desertified farmlands and consequences for its farmers in semiarid northern Nigeria: a case study of Yambawa rehabilitation scheme. Arid Land Res Manag 17:85–101

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties-regional perspectives: Asia. In: Sivakumar MVK, Motha R (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 53–69
Stigter K (CJ) (2005) Building stones of agrometeorological services: adaptation strategies based on farmer innovations, functionally selected contemporary science and understanding of prevailing policy environments. J Agric Meteorol (Japan) 60:525–528
Stigter CJ (2007) Agrometeorological services in the context of climatic aspects of coping with crop disease risk. Paper Presented at the APN Scoping Meeting of the Project "Climate and Crop Disease Risk Management: An International Initiative in the Asia-Pacific Region", Hyderabad. Report of the Workshop, APN, Kobe, no pages
Stigter CJ, Oteng'i SBB, Oluwasemire KO, Al-amin NKN, Kinama JM, Onyewotu LOZ (2005) Recent answers to farmland degradation illustrated by case studies from African farming systems. Ann Arid Zone 44(3):255–276
Stigter K, Xie Yuanyu, Liao Zhihui, Rao Qiusheng, Li Yingchun, Zheng Dawei, Wang Shili, Ma Yuping (2008). Recent identification of two agrometeorological services in Jiangxi Province, Southern China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November
Tiffen M, Mortimore M, Gichuki F (1994) More people, less erosion. Environmental recovery in Kenya. Wiley & Sons, New York, 311pp
Winarto YT, Stigter K, Anantasari E, Hidayah SN (2008) Climate field schools in Indonesia: improving "response farming" to climate change. LEISA Mag 24(4):16–18

III.3.5.(ε) Improving Coping Strategies with Weather and Climate Risks in Agricultural Production, Including the Improved Use of Insurance Approaches: Multiple Cropping

Kees Stigter

As we consider "mimicking nature" part of sustainable agriculture designs (e.g. Lefroy and Hobbs 1998; Van Noordwijk and Ong 1999; Elevitch and Wilkinson (1999–2008), ways in which nature survives weather and climate onslaughts can be used to improve coping strategies with their risks in agricultural production. Weather and climate risks related protective uses of perennials and other multiple cropping in ecologically based agriculture as listed by Altieri (1999), that we mentioned in Sect. III.3.5.(α), were (a) soil improvement (e.g. Boffa 1999 for parklands and PTFM 2008 for watersheds); (b) erosion control, including drought control (e.g. Lefroy 2001; DFID 2004a); (c) frost protection (Snyder 2001); (d) flood/runoff control (CIFOR/FAO 2005); (e) wind protection (e.g. Stigter 1984); (f) weed/disease/pest control (e.g. De Melo-Abreu et al. (2010) for pests).

Taking away these functions and introducing high dependence on artificial water applications and other artificial inputs (e.g. Bandara 2007) changes the direction of coping strategies for farmer households fundamentally (e.g. Sachs 2005). But these functions also improve the coping strategies with weather and climate risks. It would be very helpful if the multiple cropping systems we are eying could be modeled (see Box III.3.24).

Not always are weather and climate prime sources of the problems. In southern Orissa, India, the conservation, regeneration and development of forest resources by the government has not been combined with efforts to alleviate poverty and meet livelihood needs. Instead, the poor have been alienated from their resources. This has set up a downward spiral of overuse of resources (by both the poor and the rich), deprivation, further extraction of resources, increased control by the state (for conservation) and then further degradation through the clearing of the forest for crop cultivation (Scott 2006). These are factors that have to be added to the climatic ones, including recent changes (Adger et al. 2003).

K. Stigter (✉)
Agromet vision, Bruchem, The Netherlands; Agromet vision, Bondowoso, Indonesia; Retired from Wageningn University (Wageningn UR), Wageningn, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_46,

Box III.3.24

Basically we talk conservation here by “mimicking nature”. It would be very helpful if the multiple cropping systems we are eying could be modeled like the conservation measures that are tested with the Soil and Water Assessment Tool (SWAT) model (TWRI 2007). SWAT is a sophisticated computer model that predicts the impacts of weather, soils, land use and land management on water supplies as well as nonpoint and point source pollution in small to large watersheds. Information such as rainfall amount, soil type, and the amount of nutrients and pesticides applied to the land over the years are fed into the model. In the early 1990s, the researchers sold the idea of using an Erosion Productivity Impact Calculator (EPIC), SWAT and GIS to model the 48 contiguous US states, simulating the effects management activities have on water quantity and quality in watersheds (TWRI 2007). It would be extremely profitable as this could be adapted to tropical multiple cropping conditions. Connections with Agroforestry Systems models (e.g. PFTM 2008) may be possible.

Identifying weather risk for an agricultural grower or producer involves defining the time period during which risk is prevalent, and identifying a measurable weather index that is strongly correlated to farmers’ losses on a particular crop. This is the most critical process in designing a weather risk management strategy (UNESA 2007). A weather index can be constructed using any combination of measurable weather variables, over any period of time and any number of weather stations that best represent the risk to the agricultural end user. Common variables include temperature and rainfall.

After gathering the weather data, designing an index will imply looking at how the weather variables have or have not influenced yield over time; discussing key weather factors with experts such as agro-meteorologists and farmers; and referring to crop growth models which use weather variables as inputs for yield estimation (UNESA 2007). It might be that multiple cropping systems are less vulnerable than monocropping systems. But with modifications in the approach, insurances could also for them be considered an alternative, particularly if not crop or farm losses but extreme events would become the yardstick (see Box III.3.25). Farm specific agro-advisory and monitoring systems (e.g. Reddy and Reddy 2006; Bengelstorff 2008) appear less suitable mechanisms for insurances in multiple cropping.

However, along with such insurances, it is high time to utilize all available information in preparing, transferring, establishing and validating weather based agro-advisories and agrometeorological services, both for single locations and on a meso or regional scale, for in-season agricultural operations, as required to acquire as sustainable as possible an agricultural development (e.g. Singh et al. 2008; WMO 2010).

Box III.3.25

Recognizing the seriousness of climate and weather related risks to small farmers, the World Bank is exploring how to provide insurance based on weather events rather than actual crop losses. Studies are being undertaken in four countries – Ethiopia, Morocco, Nicaragua and Tunisia – to see if weather insurance is feasible. Insurance will be sold in standard units (for example, US$10 or US$100) and insurers will pay out for events such as extreme weather (for example, where rainfall is 20 or 30% below the norm) that can be measured at a regional weather station (see also Lilleor et al. 2005). The advantage of substituting crop insurance with this weather insurance approach is that everyone receives the same payout per unit of insurance. Therefore, there is no need to write individual contracts or assess individual claims, thus reducing costs (DFID 2004b).

References

Adger WM, Huq S, Brown K, Conway D, Hulme M (2003) Adaptation to climate change in the developing world. Prog Dev Stud 3:179–195

Altieri MA (1999) Multifunctional dimensions of ecologically-based agriculture in Latin America. FAO/Netherlands Conference on the Multifunctional Character of Agriculture, Maastricht. http://csdngo.igc.org/agriculture/agr_altieri2.htm

Bandara JMRS (2007) Nature farming. Integration of traditional knowledge systems with modern farming in rice. Shortened version. Endog Dev Mag (Compas) 1:8–10

Bengelstorff A (2008) Farmers can benefit from micro-insurance. The Organic Farmer Nr. 39. http://www.infonet-biovision.org/res/res/files/1924.org_farmer39_08_red.pdf

Boffa J-M (1999) Agroforestry parklands in Sub-Saharan Africa. FAO Conservation Guide 34, Rome, 230pp

CIFOR/FAO (2005) Forests and floods. Drowning in fiction or thriving on facts? RAP Publication 2005/03 (Forest Perspectives 2). CIFOR, Bogor, Indonesia and FAO, Regional Office for Asia and the Pacific (RAP), Bangkok. http://www.fao.org/docrep/008/ae929e/ae929e00.HTM

DFID (2004a) The impact of climate change on the vulnerability of the poor. DFID Key Sheet on Climate Change and Poverty no 3. http://www.dfid.gov.uk/pubs/files/climatechange/3vulnerability.pdf

De Melo-Abreu JP, Daldoum MA, Andrews PL, Bastos TX, De Groot WJ, Fleming R, Fleming R, Fujioka F, Goldammer JG, Govind A, Harrison J, Keenan T, Price D, Statheropoulos M, Stigter K, Wain A (2010) Applications of meteorology to forestry and non-forest trees. Chapter 11 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

DFID (2004b) Adaptation to climate change: can insurance reduce the vulnerability of the poor? DFID Key Sheet on Climate Change and Poverty no 8. http://www.dfid.gov.uk/pubs/files/climatechange/8insurance.pdf

Elevitch C, Wilkinson K (1999–2008) Agroforestry – A way of farming that can work for everyone. Paper 7 In: Elevitch CR (ed) The overstory book. Cultivating connections with trees, 2nd edn. PAR, Holualoa, USA. http://agroforestry.net/overstory/overstory7.html

Lefroy EC (2001) Applying ecological principles to the re-design of agricultural landscapes. The Australian Society of Agronomy. http://www.regional.org.au/au/asa/2001/plenary/4/lefroy.htm
Lefroy EC, Hobbs RJ (1998) Agriculture as a mimic of natural ecosystems. Workshop Report for the RIRDC/LWRRDC?FWPRDC Joint Venture Agroforestry Program, Williams, Western Australia. http://www.rirdc.gov.au/reports/AFT/UWA-38A.doc
Lilleor HB, Gine X, Townsend RM, Vickery J (2005) Weather insurance in semi-arid India. World Bank, New York. http://siteresources.worldbank.org/INTAMSTERDAM/Resources/GinePaper.pdf
PTFM (2008) Restoring the functions of watersheds. Policy briefs 09. Partnership for the Tropical Forest Margins. Nairobi, Kenya. http://www.worldagroforestrycentre.org/downloads/publications/PDFs/BR08143.PDF
Reddy GS, Reddy PK (2006) Efficient implementation of agri-insurance schemes by piggy-backing eSagu system. Third National Workshop on "ICT and Agriculture: From Potential to Prosperity in a Global Perspective", IAITA and DA-IICT, Ahmedabad, India, June. http://www.iiit.net/∼pkreddy/pkreddypapers/AbstracteSaguInsuranceMay24.txt
Sachs J (2005) The end of poverty. Economic possibilities for our time. Allen Lane, London, 396pp
Scott L (2006) Chronic poverty and the environment: a vulnerability perspective. CPRC WP 62, ODI, London. http://www.chronicpoverty.org/pdfs/62Scott.pdf
Singh S, Brunini O, Singh D, Abramides PG, Rolim G, Pântano AP, Blain GC, Brunini APC, Ribeiro RV (2008) Online outreach of integrated weather based agricultural information system for sustainable agriculture through regional approach. Agrometeorological Series/2008/IAC/CIIAGRO-1, Campinas, Sao Paulo, Brazil, 12pp
Snyder RL (2001) Principles of frost protection. http://biomet.ucdavis.edu/frostprotection/Principles%20of%20Frost%20Protection/FP005.html
Stigter CJ (1984) Wind protection in traditional microclimate management and manipulation: examples from East Africa. In: Grace J (ed) The effects of shelter on the physiology of plants and animals. Progress in Biometeorology Vol. 2. Swetz and Zeitlinger, Lisse, pp 145–154
TWRI (2007) Mimicking nature. Computer model helps manage nation's, world's waters. Texas Water Resources Institute. http://twri.tamu.edu/news/2007/09/20/mimicking-nature/
UNESA (2007) Developing Index-based insurance for agriculture in developing countries. UNESA Sustainable Development Innovation Brief No 2. http://www.un.org/esa/sustdev/publications/innovationbriefs/no2.pdf
Van Noordwijk M, Ong CK (1999) Can the ecosystem mimic hypotheses be applied to farms in African savannahs? Agrof Syst 45: 131–158
WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by C.J. Stigter. WMO, Geneva, in press

III.4 Applied Forest (Agro)Meteorology

III.4.1 Strategic Use of Climate Information

III.4.1.(a) Combating Disasters in Forestry and Its Protection Functions

Dick Felch

Climate related disasters in forestry can take many forms, including the frequency of severe weather events (blow downs and lightning), the occurrence of disease and insect outbreaks, the intensity and duration of critical fire weather events. In the longer term we are talking about changes in optimal growing areas, the type of species that can be grown, and changes in the overall hydrological cycle of a region (Mote et al. 2003).

For forestry, the climate change-induced modifications of frequency and intensity of forest wildfires, of outbreaks of insects and pathogens, and of extreme events such as high winds, may be more important than the direct impact of higher temperatures and elevated CO_2 (Kirilenko and Sedjo 2007). General warming is likely to encourage northern expansion of southern insects, while longer growing seasons are likely to allow more insect generations in a given season. Forests that are moisture stressed are often more susceptible to attacks by insects such as bark beetle, spruce budworms, although the timing and magnitude of the effects vary greatly (Thomson et al. 1984; Swetham and Lynch 1993).

The impact on key natural resources can be quantified to estimate sensitivity to changes in regional climates. Our understanding of past climate also illustrates the responses of human management systems to climatic stresses, and suggests that a warming of the rate projected would pose significant challenges to the management of natural resources (Mote et al. 2003). See also Box III.4.1.

Box III.4.1

As our understanding of some of the factors affecting climate are better understood, it will become possible to incorporate longer term climatic forecasts. An example would be the El Nino Southern Oscillation (ENSO), with its

D. Felch (✉)
National Weather Service, NOAA (retired), Chanhassen, MN, USA
e-mail: dickfrom@gmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_47,

relatively short return cycles, and the Pacific Decadal Oscillation (PDO), which has a cycle of 25–30 years in northwestern North America (Mote et al. 2003). In this example these two climate patterns are useful in at least two ways. First they provide some of the best predictability in seasonal forecasts of any mid-latitude location. Second the multi-decadal timescale of the PDO may provide a useful surrogate for anthropogenic climate change. It could also provide planning guidance for those extended periods of warmer and cooler conditions which will for example strongly influence the characteristics of the hydrological cycle.

By taking climate forecasts into account and adjusting operational practices to reflect potential conditions, resource managers are better positioned to meet their resource management objectives. However, most planners currently (at least in the Pacific northwest of the United States) have few plans for adapting to or mitigating the ecological and economic effects of climate change and/or variability until researchers can provide specific information. This appears to be largely due to the lack of quantifiable connections between climatic change or climatic variability and the ultimate impacts on forest yields (CIG 2009). See also Sect. III.4.1.(g). These relationships are also confounded, as discussed in Sect. III.4.1.(b), by the fact that forest systems themselves can have a distinct impact on local climates and regional climates.

The vulnerability of forest ecosystems to climatic variation and change is determined by its sensitivity to climatic variation and by its adaptability or resilience. As noted by the IPCC (2001) "Experience with adaptation of climatic variability and extremes can be drawn upon to develop appropriate strategies for adapting to anticipated climatic change." For a given decision making process dealing specifically with forest resources, it is important to:

- recognize the sensitivity to the influence of climate. Managers of forest resources have been reluctant even to recognize sensitivity to climatic variation. Research demonstrates (Peterson and Peterson 2001) that year to year and decade to decade climatic variation affects tree growth and suggests that seedlings are vulnerable to a single year of poor growing conditions, possibly leading to a costly stand failure. But forest managers tend to dismiss such research as irrelevant because of the long life span of the tree. This is a 40 year process and stand loss is considered a random event. The main reason is the lack of quantitative connections between seasonal climatic variation and timber harvest operations;
- adapt forest management operations to take into account seasonal variation in weather and climatic conditions. Whether it is seeding operations (Peterson and Peterson 2001) or harvest operations (Mote et al. 2003) or fire weather management, logical steps can be taken to protect the forest crop. The greatest interest was and is in the area of fire weather forecasting.

In summary, the life cycle of a forest spans years and even decades during which the system is exposed to a range of climatic conditions. Climatic variability, and the potential for longer term climate change during that period, makes forest management decisions difficult. There are numerous opportunities to incorporate climate information in the strategic planning process. However, the relationships between those changes and their consequences still need to be quantified to a greater degree to convince many decision makers of the true value of that information.

References

CIG (2009) Planning for climate variability and change. Climate Impact Group (CIG). Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Ocean (JISAO), University of Washington. http://cses.washington.edu/cig/fpt/planning.shtml

IPCC (2001) Climate change 2001-The scientific basis. Cambridge University Press, Cambridge. http://www.grida.no/publications/other/ipcc%5Ftar/?src=/CLIMATE/IPCC_TAR/wg1/518.htm

Kirilenko A, Sedjo RA (2007) Climate change impacts on forestry. Proc Natl Acad Sci 104: 19697–19702. http://www.pnas.org/content/104/50/19697.full.pdf+html

Mote PW, Parson EA, Hamlet AF, Keeton W, Lettenmaier D, Mantua N, Miles EL, Peterson DW, Peterson DL, Slaughter R, Snover AK (2003) Preparing for climatic change: the water, salmon, and forests of the Pacific Northwest. Clim Change 61:45–88

Peterson DW, Peterson DL (2001) Mountain hemlock responds to climatic variability at annual and decadal scales. Ecology 82:3330–3345

Swetham TW, Lynch AM (1993) Multicentury regional scale patterns of Western Spruce Budworm outbreaks. Ecol Monog 63:399–424

Thomson AR, Shepherd RF, Harris JWE, Silversides RJ (1984) Relating weather to outbreaks of Western Spruce Budworm in British Columbia. Can Entomol 116:375–381

III.4.1.(b) Selection Processes of (Changes in) Land Use and Afforestation Patterns

Ahmad Ainuddin Nuruddin

It is well known that forest ecosystems provide important functions in global and regional climate by strongly influencing the exchanges of energy and moisture between the earth's surface and the adjacent atmosphere (e.g. Taylor and Lebel 1998). The protective cover of the forest canopy influences the physical characteristics of the land surface such as albedo, rainfall interception and surface roughness (e.g. Xue and Shukla 1994). Changes in the physical properties of a forested area such as the removal of forest canopy by natural disturbances such as fire or anthropogenic causes (e.g. Shine and Forster de 1999) will cause changes in the surface albedo thus causing radiative-forcing change affecting the regional radiation balance (IPCC 2001).

Forest ecosystems also play an important role in the hydrological cycle (e.g. Bonan 2008; Sheil and Murdiyarso 2009). The ability of trees to absorb water helps in the process of change from liquid water to water vapour, which change plays an important role in the global hydrological processes (e.g. Chang 2003). Evapotranspiration represents 60–75% of precipitation inputs at the global scale (Vörösmarty et al. 1998) and is also an indicator of ecosystem productivity and biodiversity (Currie 1991). Even more importantly, new theories developed by Makarieva et al. (2006) and Makarieva and Gorshkov (2007) suggest that the traditional knowledge that forests have a positive influence on precipitation on several scales could well be true. It is suggested by these recent hypotheses that forests attract moist air, with much influence on continental and local rainfall patterns (Sheil and Murdiyarso 2009). See Box III.4.2.

Forest ecosystems are also important in stabilizing the soil. The canopy of the forest intercepts an amount of rainfall that ranges from 20 to 30% of total rainfall (Chang 2003). The canopy also reduces the energy of the rainfall and this reduces the power of erosivity of the rain. The litter covering the surface of the soil in the forest also acts as an additional protective layer from the falling rain and as a sponge

A.A. Nuruddin (✉)
Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, Serdang, Selangot, Malaysia
e-mail: aiuddin@forr.upm.edu.my

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_48,

absorbing some of the water, thus, assisted by friction, reducing the amount of surface runoff. The roots of the trees growing in the forest help to hold the soil in place, reducing the sediment and nutrient inputs into water.

Human activities over the last thousands of years have threatened the forest ecosystem (e.g. FAO 2009). With increasing numbers and mechanization/industrialization of course increasingly so (see also Box III.4.5 belonging to Sect. III.4.1.(d)). Deforestation, the conversion of forest ecosystems to other land use, such as in urbanization and agriculture, has led to an increase of greenhouse gas emissions. It has also led to changing surface characteristics of the landscape, altering the albedo and energy balances of the areas.

Simulation studies by Shukla et al. (1990) in the Amazon showed that when the tropical forests in the model were replaced by degraded grass (pasture), there was a significant increase in surface temperature and a decrease in evapotranspiration and precipitation over Amazonia. This will cause the Amazon to become drier and susceptible to forest fire (Cochrane and Barber 2008). This is fully in line with the reasoning in Sheil and Murdiyarso (2009) given in Box III.4.2.

Box III.4.2 (Contributed by Kees Stigter)

The role of vegetation in the earth hydrological cycle remains controversial. Local people in many partially forested regions believe that forests "attract" rain, but climatology had until recently no scientific explanation for that believe. (I have heard these believes expressed myself regularly in Africa and Asia when having discussions with local farmers. I could only answer that there was no theory to explain this, particularly not as a local scale effect. KS.) A new hypothesis suggests that these local people may be correct and that forest cover plays a much greater role in determining rainfall than previously recognized. Deforestation has already reduced vapor flows derived form forests by almost 5% per year with little sign of slowing. The need for understanding how vegetation cover influences climate has never been more urgent. Makarieva et al. (2006) and Makarieva and Gorshkov (2007) have developed a hypothesis to explain how forests attract moist air and how continental regions such as the Amazon basin remain wet. The implications are substantial.

The above and what follows is based on or taken from Sheil and Murdiyarso (2009), who have attempted to explain the basic ideas of Makarieva and Gorshkov and their significance for a wider audience. See also Hance (2009) and Pearce (2009) about this paper. They state that deforestation has been implicated as contributing to declining rainfall in various regions (including the Sahel, West Africa, Cameroon, Central Amazonia, and India), as well as weakening monsoons, but the links remained uncertain. Observations suggest that extensive deforestation often reduces cloud formation and rainfall, and accentuates seasonality. Forest clearings can cause a distinct, convection driven "vegetation breeze" in which moist air is drawn out of the forest.

Atmospheric turbulence resulting from canopy roughness and temperature driven convection are thought to explain the localized increase in rainfall sometimes associated with fragmented forest cover. Much of the latter statements were taken by Sheil and Murdiyarso (2009) from Bonan (2008). Researchers have previously puzzled over a missing mechanism to account for observed precipitation patterns and Makarieva and Gorshkov's hypothesis offers a solution they call a "pump".

Pressure gradients driven by temperature and convection are considered to be principal drivers of air flows in conventional meteorological science. Makarieva and Gorshkov argue that the importance of evaporation and condensation have been overlooked. At the global average lapse rate water vapour rises and condenses. The reduction in atmospheric volume that takes place during this gas to liquid phase change causes a reduction in air pressure. This drop in pressure has routinely been overlooked. So atmospheric volume reduces at a higher rate over areas with more intensive evaporation. The resulting low pressure draws in additional moist air from areas with weaker evaporation. This leads to a net transfer of atmospheric moisture to the areas with the highest evaporation. Sheil and Murdiyarso (2009) discuss various local consequences. Forest loss and diminished evaporation can for example reduce the penetration of monsoon rains and reduce the duration of the wet season. Clearing enough forest within a larger forest zone may switch net moisture transport "from ocean to land" into "from land to ocean", leaving forest remnants to be dessicated. Clearing a band of forest near the coast may suffice to dry out a wet continental interior.

Makarieva and Gorshkov's hypothesis suggests that forest loss will be associated with a loss of stabilizing feedbacks and increased climatic instability. In Brazil's Atlantic forests just such a correlation has been detected between reduced tree cover and increased local interannual variation in rainfall. Have forests evolved to generate rain? This idea touches on the much-debated possibilities of emergent self-stabilizing behavior (or "Gaia"). Trees and forests have evolved numerous times in the history of the earth, suggesting a repeated trend to generate rich self-watering terrestrial habitats. There is scope for self-stabilizing interactions to arise. We need to unravel the feedback processes and thresholds that operate spatially at different scales, and the influences that act upon them.

Acceptance of the biotic pump would add to the values that society places on forest cover. By raising regional concerns about water, acceptance of the biotic pump demands attention from diverse local actors, including many who may otherwise care little for maintaining forest cover.

Forest harvesting activities will result in removal of selected and marked trees and will result in crown loss and changes in forest dynamics. These changes will often have long term influences. A study by Okuda et al. (2003) in Malaysian Diptercarp lowland tropical forest showed that the effects of more than 40 years of selective logging on canopy and stand structure and on tree species composition were evident. The study also showed that the average size of canopy crowns was much smaller in the regenerating forest than in the primary forest. Removal of the trees and reduction of basal area cause a reduction of leaf area index and an increase in canopy openness. The removal of the crown allows more direct solar radiation to reach the forest floor and increase in air temperature (e.g. Dignan and Bren 2003). This will also lead to a decrease in the relative humidity.

Afforestation and forest rehabilitation are approaches to improve (partially) deforested and abandoned degraded land areas. The goal of forest rehabilitation is to mimic and hasten the natural successional processes (Miyawaki 1999; Lamb 2002) and ultimately achieve climax stage. As the rehabilitated areas go through the induced successional stages (Lamb and Gilmour 2003), the changing microenvironment (Balandier et al. 2009) will also influence the physiological processes, regeneration and growth of the trees in the rehabilitated forests (Meyer et al. 2001).

Forest plantation involves planting of monoculture high quality timber species with expected higher yield compared to the natural forest. In order to maintain high yield, species suitable for the site are planted and silvicultural activities are conducted to ensure that the trees receive optimum solar radiation for photosynthesis and enough soil moisture for growth.

One of the main silvicultural activities conducted in forest plantation is thinning, that is removing some trees from a forest stand to increase growing space, reduce competition and allow the remaining trees to grow faster (Smith et al. 1997). This again results in changes in the microclimate which lead to major changes in the ecophysiological behavior of the trees (Aussenac 2000). Thinning increases light (Wetzel and Burgess 2001), air temperature (Weng et al. 2007), soil moisture (Breda et al. 1995) and nutrient availability for overstorey and understorey vegetation.

The improvement in light, moisture and nutrient availability is short-lived as canopy closure and root development fill in this newly available growing space. As a consequence, the longevity of any effects on microclimate and resource availability in a stand will depend on the intensity and frequency of thinning, of which the effects remain modified by site factors and plant species behavior.

References

Aussenac G (2000) Interactions between forest stands and microclimate: ecophysiological aspects and consequences for silviculture. Ann For Sci 57:287–301

Balandier P, Frochot H, Sourisseau A (2009) Improvement of direct tree seeding with cover crops in afforestation: microclimate and resource availability induced by vegetation composition. For Ecol Manag 257:1716–1724

Bonan GB (2008) Forests and climate change: forcing feedbacks and the climate benefits of forests. Science 320:1444–1449

Breda N, Granier A, Aussenac G (1995) Effects of thinning on soil and tree water relations, transpiration and growth in an oak forest (Quercus petraea (Matt.) Liebl. Tree Physiol 15:295–306

Chang M (2003) Forest hydrology: an introduction to water and forests. CRC Press LLC, New York, 373pp

Cochrane MA, Barber CP (2008) Climate change, human land use and future fires in the Amazon. Glob Change Biol 15:601–612

Currie DJ (1991) Energy and large-scale patterns of animal and plant species richness. Am Nat 137: 27–49

Dignan P, Bren L (2003) A study of the effect of logging on the understory light environment in riprarian buffer strips in a south-east Australian forest. For Ecol Manag 172:161–172

FAO (2009) Promoting sustainable management of forests and woodland. http://www.fao.org/forestry/sfm/en/

Hance J (2009) Revolutionary new theory overturns modern meteorology with claim that forests move rain. http://news.mongabay.com/2009/0401-hance_revolutionarytheory.html

IPCC (2001) Climate change 2001: The sientific basis. Cambridge University Press, Cambridge, 850pp

Lamb D (2002) Large-scale ecological restoration of degraded tropical forest lands: The potential of timber plantations. Restor Ecol 6:271–279

Lamb D, Gilmour D (2003) Rehabilitation and restoration of degraded forests. IUCN, Gland and Cambridge, and WWF, Gland, Switzerland, 119p

Makarieva AM,GorshkovVG (2007) Biotic pump of atmospheric moisture as driver of the hydrological cycle on land. Hydrol Earth Syst Sci 11:1013–1033

Makarieva AM, Gorshkov VG, Li BL (2006) Conservation of water cycle on land via restoration of natural closed-canopy forests: implications for regional landscape planning. Ecol Res 21: 897–906

Meyer CL, Sisk TD, Covington W (2001) Microclimatic changes induced by ecological restoration of Ponderosa Pine forests in Northern Arizona. Restor Ecol 9:443–452

Miyawaki A (1999) Creative ecology: restoration of native forests by native trees. Plant Biotech 16:15–25

Okuda T, Suzuki M, Adachi N, Quah ES, Nor Azman H, Manokaran N (2003) Effect of selective logging on canopy and stand structure and tree species composition in a lowland dipterocarp forest in peninsular Malaysia. For Ecol Manag 75:297–320

Pearce F (2009) Rainforests may pump wind worldwide. http://www. newscientist.com/article/mg20227024.400-rainforests-may-pump-winds- worldwide.html?full=true

Sheil D, Murdiyarso D (2009) How forests attract rain: an examination of a new hypothesis. Bioscience 59:341–347

Shine KP, Forster PM de F (1999) The effect of human activity on radiative forcing of climate change: a review of recent developments. Glob Planet Change 20:205–225

Shukla J, Nobre C, Sellers P (1990) Amazon deforestation and climate change. Science 247: 1322–1325

Smith DM, Larson BC, Kelty MJ, Ashton PMS (1997) The practice of silviculture: applied forestry ecology. Wiley, New York, 537pp

Taylor CM, Lebel T (1998) Observational evidence of persistent convective-scale rainfall patterns. Mon Weather Rev 126:1597–1607

Vörösmarty CJ, Federer CA, Schloss AL (1998) Potential evaporation functions compared on US Watersheds: Possible implications for global-scale water balance and terrestrial ecosystem modeling. J Hydrol 207:147–169

Weng SH, Kuo SR, Guan BT, Chang TY (2007) Microclimatic responses to different thinning intensities in a Japanese cedar plantation of northern Taiwan. For Ecol Manag 241:91–100

Wetzel S, Burgess D (2001) Understorey environment and vegetation response after partial cutting and site preparation in Pinus strobus L. stands. For Ecol Manag 151:43–59

Xue Y, Shukla J (1994) The influence of land surface properties on Sahel climate. Part II: afforestation. J Climate 9:3260–3275

III.4.1.(c) The Selection of Actual Preparedness Strategies for Dealing with Climate as Adopted in Forestry

Al Riebau

Forestry preparedness strategies for climate change are challenging. Governments are now developing plans to mitigate climate change by various schemes for regulating the emissions of green house gases, primarily in the form of limited emissions of carbon dioxide. This issue has become so politically divisive that actions to prepare for a changing climate are in danger to get lost in the emissions debate. Preparedness decisions in forest meteorology universally call for making predictions concerning future weather and climate states (see Box III.4.3).

Box III.4.3

The United States National Oceanic and Atmospheric Administration (NOAA) Climate Variability and Predictability (CVP) program seeks to observe, model and understand patterns of climate variability on intra-seasonal and longer time scales and to assess predictability of such climate variability. The ultimate goal of the program is to develop skilful predictions of climate variability and change on intra-seasonal to multi-decadal time scales and regional spatial scales for optimal use in preparedness strategies for resource planning and policy decision making (Fig. III.4.1). NOAA's CVP research focuses on large-scale recurrent patterns of variability that influence climate on the regional scale, particularly over the US. Among these patterns are the El Niño-Southern Oscillation (ENSO), Pacific Decadal Variability (PDV) [PDO is the dominant PDV, Yeh and Kirtman (2004)], Tropical Atlantic Variability (TAV) and the North Atlantic Oscillation (NAO)/Northern Hemisphere Annular Mode (NAM) (NOAA 2008). There is now compelling evidence that some natural climate variations, such as ENSO, PDV, and the NAO/NAM, which may themselves be changing in frequency of occurrence,

A. Riebau (✉)
Retired from USDA Forest Service Research and Development, Nine Points South Technical PTY LTD, Clarkson, WA, Australia
e-mail: ariebau@ninepointsouth.com.au

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_49,

can significantly alter the behaviour of extreme events, including floods, droughts, hurricanes and cold waves (IPCC 2001a, b).

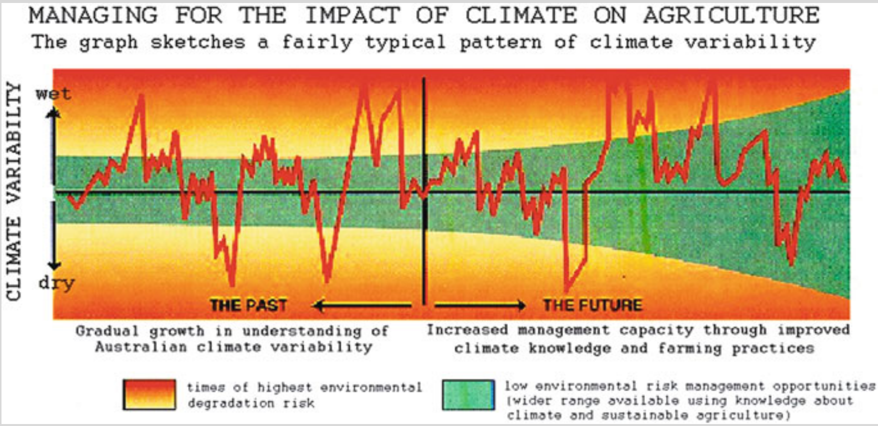


Fig. III.4.1 Sustainable development requires improved management in all climate ranges, especially during climate extremes, which bring the greatest risk of environmental degradation. The diagram suggests how improved climate understanding and forecast skill may increase the range of low-risk situations, and enhance our ability to manage high-risk situations (BOM 2009)

Overall, the climate issues which immediately challenge forests are increases in disease out-breaks, increases in forest fire occurrence and intensity, and direct forest damage from increased frequency of severe weather events. These are all phenomena that can be linked to climate variability. Generally, detection of climate variability in a useful manner for forestry involves detection of the beginning of El Niño Southern Oscillation (ENSO) or other large scale ocean circulation events. Such events, detected in their beginning phases, have significant and at least somewhat predictable consequences on the continents, which can be better prepared for and managed with this fore-knowledge.

As will be argued in Sect. III.4.2.(iii), detecting climate change against natural variability is a great scientific challenge. Paradoxically, climate change mitigation and preparedness may open new markets for forestry in carbon sequestration (see also Sect. III.4.5.(ε)) and production of fuels (e.g. Stigter et al. 2010). For example, high oil content mallee species in Western Australia are being researched as fuel source for electric power generation, with a view that changing climate will not only make the product itself more desirable but also make the trees more climatically adapted to sites in the state and nation-wide (Abadi et al. 2009).

A new approach to preparedness strategies that could be adopted is to consider forests more from a systems ecology perspective when considering forest climate change adaptive strategies. Systems ecology focuses on interactions and transactions within and between biological and physical components, and is especially concerned with the way the functioning of ecosystems can be understood and represented mathematically.

In such a viewpoint, forests are viewed as being systematic (composed of interrelated features and flows of both energy and material) and their health is quantifiable as a systematic whole. Remote sensing techniques, when combined with a systems ecology viewpoint could for example provide a synergism in managing alpine forest ecosystems (Riebau 2004).

Visualization of such a conceptual framework is naturally easier when presented spatially. If a comprehensive mapping of forest biomes were done for a forested region, climate controls could be established for each biome. Of the existing classification systems, the Global Ecological Zone (GEZ) system (developed by FAO for the Forest Resources Assessment 2000 report FAO 2000) was developed for forestry purposes. It builds on widely accepted precedents, is well harmonized between countries and regions, is of relatively high resolution, and is available in digital format (Rakonczay 2002). By using the GEZ system, or another system that appropriately uses climate information, to be prepared the adaptive "fit" of a forest biome could be assessed against projections for climate change. Human influences on the earth's biomes may require a new conceptual approach to viewing our relationship to the planet (see Box III.4.4).

Box III.4.4

The scale of climate change is planetary. Adapting to climate change, even on the scale of a forest, will need new adaptive approaches that must be based on a new world view. Some climate researchers have suggested that we adopt the term "Anthropocene" to recognize that the geologic epoc name Holocene no longer describes our vastly human dominated globe (Nature 2003).

Foresters will be hindered in designing effective adaptation strategies if such strategies are based on a limited vision founded on outmoded views of the environment. Environmentalism, although a progressive force in the past decades in richer countries and a great influence on forestry policies, has perhaps out-worn its conceptual foundations as an effective movement to combat climate change in the USA (Shellenberger and Nordhaus 2005). Environmentalism has been too often based on a simplistic fantasy that the world can be managed to return to a "natural state" and that achieving this would improve the fortunes of people (Crichton 2003).

Adaptation of forestry to climate change must be placed within a larger context, that of planetary engineering. "Terraforming" (literally, "earth-shaping") of a planet, moon, or other body is the hypothetical process of deliberately modifying its atmosphere, temperature, surface topography or ecology (including human socio-ecology) to be similar to those on Earth to make it habitable by humans. Human caused adverse climate change will likely result in humanity being forced to make the earth to become the first planet to be "terraformed". A new natural resources management should then develop within a new paradigm of Earth Systems Engineering and Management (Allenby 2007). If forestry is truly to adapt to changing climate, such a viewpoint will need to be embraced. The world itself is one country, and mankind its citizens (e.g. UHJ 1985).

Such an approach would incorporate that, while reasoning and objectivity as hallmarks of the scientific method are pivotal, science has increasingly been held to account for issues that are technological, social, and ethical. This is certainly true for forest managers and forest meteorologists. Some factors for evaluating science as applied to decision making for preparedness are that it should be technologically usable (for example not so advanced as not being able to be applied due to technological limitations), socially acceptable and ethical. Social acceptance and ethical discussions may at first sound far afield for practical matters such as forest meteorology. However, tactical and operational activities for forest fires and floods are examples of how controversial social and ethical considerations even for the most transparently beneficial endeavours can be (see also Chap. IV.2).

It is now fairly well established that remote sensing can be used to detect forest diseases and forest dynamics (Reich et al. 2004; Liu et al. 2003). Such techniques can also be adapted for mapping ecosystems, biomes, and other forest attributes (Qu et al. 2006). As climate modeling resolution improves geographically, new regional analyses would perhaps allow an understanding of how forest ecosystems and biomes might shift.

Analyses of potential shifts would need to be prepared based on the ecological and causative factors which allow for the ecosystem or biome and adaptive management applied (Walters 1997; Lee 1999). Such preparative analyses combined with remote sensing data derived mapping, especially in harsh or remote terrain, could be standardised to provide foresters with powerful tools to adapt management to changing conditions (Kias et al. 2004). Coupled with these approaches could be preparedness with the genetic engineering of trees to make them better adapted to changing climate conditions (Natural Resources Canada 2007).

Adapting forest management to climate change and increasing climate variability will undoubtedly be influenced by carbon sequestration policies that both constrain some actions and encourage others (California Air Resources Board 2007). According to FAO estimates (FAO 2008), the world's total forest area continues to decrease but the rate of net loss is slowing. In the period 2000–2005, 13 million hectares of forest were deforested, on average, each year. In that same period, 5.7 million hectares were added annually to the forest estate, giving a net annual forest loss of 7.3 million hectares. This was a lower rate than during the period 1990–2000. The estimated average global rate of forest carbon depletion is 1.6 gigatonnes per year, which is about 0.25% of total forest carbon (FAO 2008).

As many view reforestation as a climate change preparedness or mitigation measure, it is clear that forests must be protected. However, forest sequestration opportunities involve both ecology and economics in a manner that production foresters may be unfamiliar with. Among the key factors that affect estimates of the cost of forest carbon sequestration are (Stavins and Richards 2005):

- the tree species involved, forestry practices utilized, and related rates of carbon uptake over time;
- the opportunity cost of the land – that is, the value of the affected land for alternative uses;
- the disposition of biomass through burning, harvesting, and forest product sinks;
- anticipated changes in forest and agricultural product prices;
- the analytical methods used to account for carbon flows over time;
- the discount rate employed in the analysis;
- the policy instruments used to achieve a given carbon sequestration target

Again, no matter what incentives or policies for forest carbon sequestration that may be enacted by politicians, preparedness strategies must take into consideration that forests cannot be established on sites where climatic conditions are not suited. This issue may be particularly difficult for sites which historically were well suited for a particular forest type but may be no longer suited to forests at all (Bachelet et al. 2004).

References

Abadi A, Bartle J, Giles R (2009) Commercial feasibility of woody biomass Production in wheatbelt agriculture. Paper Presented at the Climate 21 Meeting of the Western Australia Department of Agriculture and Food, South Perth, 22pp. http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/cli/climate21_session7_abadi.pdf

Allenby B (2007) Earth systems and management: a manifesto. Environ Sci Technol 41:7960–7965. http://enpub.fulton.asu.edu/cesem/

Bachelet D, Neilson R, Lenihan J, Drapek R (2004) Regional differences in the carbon source-sink potential of natural vegetation in the USA. Environ Manag 33(Suppl 1):S23–S43

BOM (2009) Climate variability and El Nino. Australian Bureau of Meteorology (BOM). http://www.bom.gov.au/climate/glossary/elnino/elnino.shtml

California Air Resources Board (2007) Adoption of forest protocols by the California Air Resources Board, questions and answers. The Pacific Forest Trust, 4pp. http://www.pacificforest.org/policy/WFWC%20PDFs/CARB-Protocols-QandA.pdf

Crichton M (2003) Environmentalism as religion. Speech given at the Commonwealth Club San Francisco. http://www.crichton-official.com/speech-environmentalismaseligion.html

FAO (2000) Global forest resources assessment report 2000. FAO forestry paper 140, 511pp. http://www.fao.org/forestry/fra2000report/en/

FAO (2008) Strategic framework for forests and climate change. 57pp. http://www.fao.org/forestry/media/16639/1/0/

IPCC (2001a) Climate change 2001: the scientific basis. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, Van der Linden PJ, Dai X, Maskell K, Johnson CA (eds) A contribution of working group I to the third assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, 94pp

IPCC (2001b) Climate change 2001: impacts: adaptation, and vulnerability. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) Working group II. Cambridge University Press, Cambridge, 1005pp

Kias U, Franz H, Lotz A (2004) Working towards a standard for RS-based classification of land cover and biotope mapping in the alpine space. In: Wojciech W, Bytnerowicz A, Riebau A (eds) A message from the Tatra – geographical information systems and remote sensing in mountain environmental research. Institute of Geography and Spatial Management, Jagiellonian University Press, Kraków, pp 183–191

Lee KN (1999) Appraising adaptive management. Conserv Ecol 3(2):3. http://www.consecol.org/vol3/iss2/art3/

Liu J, Zhuang D, Luo D, Xiao X (2003) Land-cover classification of China based on integrated analysis of AVHRR imagery and geo-spatial data. Int J Rem Sens 24:2485–2500

Natural Resources Canada (2007) Genetic engineering for forestry in Canada. http://cfs.nrcan.gc.ca/subsite/biotechnology/genetic/3

Nature (2003) Welcome to the Anthropocene. Editorial. Nature 424:709. http://www.nature.com/nature/journal/v424/n6950/full/424709b.html

NOAA (2008) Climate variability program. http://www.climate.noaa.gov/

Qu JJ, Gao W, Kafatos M, Salomonson VV (eds) (2006) Science of satellite remote sensing, Vol 1: science and instruments. Tsinghua University Press, Beijing and Springer, Heidelberg, 418pp

Rakonczay Z (2002) Biome-specific forest definitions. UNFCCC framework convention on climate change, technical report 39, 28pp. http://www.fao.org/DOCREP/005/Y4171E/Y4171E52.htm

Reich RM, Lundquist JE, Bravo VA (2004) Spatial models for estimating fuel loads in the Black Hills, South Dakota. Int J Wildland Fire 13:1–11

Riebau AR (2004) Reflecting stars in a mountain lake. In: Wojciech W, Bytnerowicz A, Riebau A (eds) A message from the Tatra – geographical information systems and remote sensing in mountain environmental research. Institute of Geography and Spatial Management, Jagiellonian University Press, Kraków, pp 13–30

Shellenberger M, Nordhaus T (2005) The death of environmentalism. Global warming politics in a post – environmental world. Environment Press, Environmetal Grantmakers Association, 37pp (other data on copyright). http://www.thebreakthrough.org/images/Death_of_Environmentalism.pdf and http://oracle.cas.muohio.edu/ies/students2005/DeathOfEnvironmentalism.pdf

Stavins RN, Richards KR (2005) The cost of USA forest-based carbon sequestration. Pew center on global climate change, Arlington, 38pp. http://www.pewclimate.org/docUploads/Sequest_Final.pdf

Stigter K, Baier W, Barrie I, Brunini O, Dommermuth H, Gat Z, Gommes R, Keane T, Chan Ah Kee, Lomas J, Milford J, Ravelo A, Rijks D, Samui RP, Walker S, Wang Shili, Weiss A (2010) General. Chapter 1 in “Guide to Agricultural Meteorological Practices”, Third Edition, WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

UHJ (1985) The promise of world peace. Universal House of Justice (UHJ). Many countries. http://info.bahai.org/article-1-7-2-1.html

Walters C (1997) Challenges in adaptive management of riparian and coastal ecosystems. Conserv Ecol 1(2):1. http://www.consecol.org/vol1/iss2/art1/

Yeh Sang-Wook, Kirtman BP (2004) Pacific decadal variability and ENSO amplitude modulation. ftp://grads.iges.org/pub/ctr/ctr_168.pdf

III.4.1.(d) More Efficient Use of Forestry and Management Inputs

Kulasekaran Ramesh and Kees Stigter

Climate is a non monetary input influencing the performance of forest production systems for the efficient use of monetary inputs. (Micro)climatic events also largely determine the efficiency of external inputs in agriculture, forestry, animal husbandry and fisheries. In forestry, climatic information and its application to input management has immense value. From the time seeds are sown and plants establish in the field to final harvest, climatic events have a role to play (e.g. Tewari 1994).

From a development point of view, Onweluzo and Onyemelukwe (1977), talking long ago about forest influences on environmental stability, concluded that although environmental deterioration has generally been human aggravated if not human caused, there is a lot that careful planning and resource management can achieve toward the improvement of the human environment. With Nigeria as an example they argued that the forestry sub-sector had very much to contribute in this direction, given the necessary framework for coordinated cross-sectoral co-operation. They envisaged the forestry sub-sector needs for fruitful functional relationships with particularly the agricultural, manufacturing, construction, town-planning and tourism sub-sectors. They proposed in their classic approach that joint development problem-oriented projects should be used as permanent links between these relevant sub-sectors and the forestry departments. Through such development oriented links, and given the necessary financial and other resources, the forestry sub-sector should be better able to contribute more substantially to income generation towards the development and sustenance of a high quality of the human environment in its varied forms (Onweluzo and Onyemelukwe 1977). See also Box III.4.5.

In commercial forestry management, the strategic use of climate information for preparedness will in first instance be in the selection of a suitable region for a tree crop and the appropriate choice of the particular tree itself. This single decision determines the subsequent decisions for use of management inputs such as water, insecticides (pesticides, fungicides, herbicides), fertilizer and such other inputs as locally necessary for successful commercial forest production. In addition to the

K. Ramesh (✉)
IHBT(CSIA), Palampur, India; IISS(ICAR), Bhopal, India
e-mail: ramechek@yahoo.co.in

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_50,

above, extreme weather events like frost may also be alleviated by proper input management practices either monetary or non monetary.

Box III.4.5 (Contributed by Kees Stigter)

Much more than half the forests that not so long ago covered the earth is gone and deforestation is expanding and accelerating. The health and the quality of remaining forests are declining. However, our relationship to forests has evolved in some positive ways as well. In some places there has been a shift from unrestrained boom-and-bust forest exploitation and forest conversion to more sustainable forest management for a wider range of goods and services. People who have lived in and near forests for generations are being recognized as forest managers in many places, not forest destroyers. New ways of satisfying needs for forest products less wastefully are also being pursued.

Management for timber commodities and conversion of forests to other uses has reduced or curtailed the ability of forests to provide many other benefits and services. These include producing non-timber materials such as food, fodder, fish and medicines; purifying and regulating water supplies; absorbing and decomposing wastes; cycling nutrients; creating and maintaining soils; providing pollination, pest control, habitat and refuge; regulating disturbances; and regulating local and global climates. Forests also provide educational, recreational, aesthetic, and cultural benefits. They provide sustenance and livelihoods for hundreds of millions of people, including those who are excluded from the formal economy. In fact, not only are other uses than timber and pulp production often more valuable, they can be sustained over the long term and benefit more people.

Still, it is clear that the world will continue to need timber products, and that much of that need will be satisfied through commercial forest management. Thus a major focus of attention by foresters, ecologists and economists has been reforming forest practices. When an estimate was made in the late 1980s, less than one per mille of tropical forests were managed for sustained yields. Nevertheless, progress has been made in understanding complexity of forests, defining Sustainable Forest Management (SFM) and describing how it can be applied in various forest types and nations. Some of this effort has gone into developing international criteria and indicators to assess conditions in tropical, temperate, boreal and dry forests. SFM seeks to mirror the conditions of natural forests that are heterogeneous, with many species, ages and sizes. Natural disturbances are enabled and mimicked.

At the same time that foresters and ecologists have been redefining the science of forestry, many consumers have indicated they want their buying habits to be part of the solution to forest decline rather than its cause. This concern is shared by a growing number of commercial buyers and retailers. For such claims of SFM to be meaningful and credible, independent auditing and verification is necessary. This led to the establishment of the Forest Stewardship Council in 1993. Elements of this new relationship include halting forest degradation and forest conversion, restoring forest health, improving management, reducing waste and overconsumption combined with making consumption more equitable, getting the market signals right, returning the control of forests to communities, reforming and strengthening national policies as well as international agreements, and improving research and monitoring.

More investment in forest research and management is also needed. Funding for forest-related research is a small fraction of agricultural research, and both are inadequate to meet the challenges of tomorrow. There is still much to learn about forest species, functioning, and dynamics and about the best management practices. Ultimately, the effectiveness of policy, management and market reforms will be determined by whether the decline of the world's forests is arrested and reversed, and the quality of life of people who depend on them is improved. And by whether future generations inherit healthy forests.

The above material was taken from or based on a lengthy paper by Abramovitz (1998).

Water is one of the most limiting resources affecting forest establishment and productivity. High mortality in forests is a result of water scarcity during the establishment stage in forests as well as commercial tree plantations, particularly in arid regions. Nevertheless, excess watering during the early phases may result in restricted development of roots, very often leading to poor and shallow root systems. These trees become susceptible to windthrow and subsequent death, if irrigation is discontinued at later stages.

Season of planting and irrigation affected the production of bamboo culms to a great extent. Spring planting of *Bambusa tulda* with irrigation resulted in escalated growth and yield to almost double of that of non-irrigated summer plantation in Haryana, India (Aggarwal et al. 1994). Although water is necessary for higher productivity of tree crops, irrigation at the establishment stage assumes significance. Teak (*Tectona grandis*), although extensively planted in comparatively dry regions of the Indian subcontinent, has been found to suffer badly in abnormal droughts but the damage is fatal especially in young plantations (Tewari 1994).

For the establishment of tree seedlings during their early stage, construction of circular structures with a stone mulch was observed in Yunnan province (China), but simple container trickle irrigation had to be used for establishing desert trees/bushes/grasses in Sudan under extremely dry conditions (e.g. Al-Amin et al. 2005). In India, circular water harvesting was found to be useful as this serves as microcatchment for the falling rain drops (Gupta and Muthana 1985). Microcatchment water harvesting in Rajasthan (India) showed improvement in survival of neem seedlings (Gupta et al. 1995). Gupta and Sharma (1998) have found that water harvesting by circular catchments increased profile moisture storage and improved the establishment of *Prosopis cineraria*.

Other than the above mechanical measures, biological measures like mulching are also promising. Mulching with *Crotolaria burhia* (sinia) by spreading it around each plant in a circle of 1 m diameter as a 10–15 cm thick mat, to moderate soil thermal regime, improved the survival of several desert species in a sand dune of the Thar desert in India (Gupta and Singh 1997).

As of water management after the establishment phase, experiments of Bala et al. (2008) revealed that *Eucalyptus camaldulensis* at different water management regimes highlighted the importance of water added per irrigation more than the total water applied in an arid sandy loam soil in India. Field experiments at Hyderabad (India) in a sandy loam soil revealed that irrigation at 20–30 days interval was sufficient to improve teak girth and height (Bheemaiah et al. 1997).

Low soil fertility and soil moisture stress conditions are important limitations causing transplanted seedlings difficulties to establish. Application of pine needle and bansha (*Adatoda vasica*) mulch to a highly eroded sandy soil in India improved growth of pine (*Pinus roxburghii*). Effectiveness of nutrients, that is nitrogen and phosphorus, for boosting crop growth and retarding mortality, was enhanced by the application of mulch through moisture retention in the soil (Singh et al. 1994). Experiments in an arid sandy soil of Rajasthan, India indicated that nitrogen application @ 9 g/plant and phosphorus @ 6 g/plant improved the performance of *Ailanthus excelsa* (Gupta et al. 1994). Fertilized plants showed better vigor to withstand frost injury. These are all examples of more efficient use and management of inputs.

References

Abramovitz JN (1998) Sustaining the world's forests. State of the world 1998. A Worldwatch Institute Report on Progress Towards a Sustainable Society. Norton & Co, New York/London, pp 21–40

Aggarwal SG, Khullar P, Dhawan VK, Joshi SR (1994) Growth and yield of *Bambusa tulda* with irrigated and non irrigated plantations in Haryana. Ind Forester 120:477–482

Al-Amin NKN, Stigter K(CJ), Elagab MAM, Hussein MB (2005) Combating desert encroachment by guiding people, wind and sand. J Agric Meteorol (Japan) 60:349–352

Bala N, Singh G, Bohra NK, Chaudhary KR, Gupta RK (2008) Growth and biomass accumulation of *Eucalyptus camaldulensis* irrigated at different water regimes in an arid sandy plain of India. Ind Forester 134:611–621

Bheemaiah G, Subrahmanyam MVR, Ismail S (1997) Performance of Teak under different irrigation and fertilizer management practices. Ind Forester 123:1171–1175

Gupta JP, Muthana KD (1985) Effect of Integrated moisture conservation technology on the early growth and establishment of *Acacia tortilis* in the Indian desert. Ind Forester 111:477–485

Gupta GN, Singh B (1997) Relative performance of different species on a sand dune in That desert. Ind Forester 123:206–210

Gupta JP, Sharma AK (1998) Integrated effect of water harvesting and manuring on growth and establishment of Propospis cineraria in hot arid regions of Rajasthan. Ind Forester 124:54–58

Gupta GN, Premlal N, Singh N, Singh B, Bohra NK (1994) Response of Ailanthus excels to nitrogen and phosphorus fertilization on an arid sandy soil. Ind Forester 120:368–373

Gupta GN, Limba NK, Gupta PK (1995) Microcatchment water harvesting for raising neem in arid region. Ind Forester 121:1022–1032

Onweluzo BSK, Onyemelukwe JOC (1977) Forest influences on environmental stability. In: O'Keefe P, Wisner B (eds) Landuse and development. African Environment Special Report 5. International African Institute, London, pp 18–33

Singh B, Kumar P, Prasda KG, Singh RK, Malik N (1994) Effect of nitrogen, phosphorus and mulching on growth and establishment of *Pinus roxburghii*. Ind Forester 120: 242–247

Tewari DN (1994) Forests and climate. Ind Forester 120:964

III.4.1.(e) Selection of (Changes in) Livestock Management Patterns Related to Forests

Kees Stigter

An adequate supply of livestock fodder is crucial to the livelihoods of millions of people across the developing world. Livestock producers meet their fodder requirements through a combination of crop residues and grazing on common lands, private lands, forests, fallow agricultural lands and harvested agricultural lands. Availability and access to quality fodder resources and water, however, is emerging as an important constraint in livestock production. Increasing fodder shortages and water shortages are recurring phenomena, not only in arid and rain-fed regions, but also in irrigated areas and regions receiving higher rainfall.

At the same time, the shrinking of common property resources (such as forests KS) (industrial use, plantations, etc.) and the deterioration in their quality has reduced the availability of grazing lands (Hall et al. 2008). Natural resource management and environmental protection as a competency to be transferred to local governments and legislation is for example being prepared in Burkina Faso and Mali, and is suggested for Niger (Hilhorst 2008).

Measures are needed to share resources. Wassie Eshete (2007), of which parts were summarized in Wassie Eshete et al. (2009a, b), analyses the effects of microsites, of management and of exclosures on the regeneration of main church forest tree species in the highlands of northern Ethiopia. A strict experimental setup was used. The results suggest that simple measures may improve seedling establishment, and that, for some species, forest edges are particularly useful for growth and survival after successful establishment (see also Geiger et al. 1995 for the microclimate aspects KS).

Control of livestock pressure is necessary. Seeds dispersed outside the forest will not have a chance to establish seedlings, grow and colonize the surroundings. Livestock grazing thus has a paramount impact on the long-term sustainability of church forests and their role in restoring the degraded surroundings. Together with erecting fences, seed sowing, planting seedlings and soil scarification may contribute

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_51,

to maintain and restore Church forests in the fragmented landscapes of northern Ethiopia (Forest Ecology and Forest Management Group 2009).

Examples from Hudak (2000) show that interactions of livestock and wildlife with (measures taken in) forested areas are complicated. On the overgrazed lands of the southwest in the western states of the US, fire suppression has allowed woody species such as big sagebrush, pinyon pine, and juniper to invade millions of acres of what were previously grasslands or mixed grassland/shrublands, profoundly changing their ecological characteristics.

Negative effects of prescribed burning are among others that cause in forests a reduction to occur of foliage height diversity, creating a 2-layered instead of multi-layered forest, with attendant reduction in wildlife diversity. Alteration of dynamics of upland forests of the interior West of the US occurs by reducing the abundance of fine fuels which formerly carried frequent, low-intensity fires through forests.

Livestock contributes to the formation of shade tolerant, but fire sensitive dense stands highly susceptible to damage by insects and pathogens. This further contributes to the likelihood of stand replacing fires. An example of the difference in forest density that can result from livestock grazing is that two areas, distinguished only by the grazing of livestock, differed markedly in the density of small-diameter trees: 85 per acre in the ungrazed region compared to 3,290 per acre in the grazed area. Because of this and many other livestock related arguments, Hudak (2000) concludes that the environmental damage inflicted by livestock production on federal public lands in the USA is not justified by social nor economic benefits. He believes that the federal grazing program should be fazed out and terminated.

A special case study is given in Box III.4.6.

Box III.4.6

An interesting NGO project in Brazil has recently been described by Miranda (2009). Large carnivores, mainly jaguars but also pumas, are loosing their habitats in marginally flooded, open semi-deciduous forest in the Pantanal region, Mato Grosso do Sul state, of Brazil, while poachers remove natural preys. Preventive measures have to be implemented to minimize predation incidents on spatially co-existing livestock on ranches (with thousands heads of cattle and restricted hunting) and to reduce jaguar mortalities due to retaliation after livestock killings. The predominant vegetation on the ranches consists of non-flooding forests, seasonally inundated grasslands and (sometimes closed) woodlands, and swamps. Riparian forest (gallery) is another type of habitat that forms contiguous corridors along the borders of streams and rivers. Such remaining habitat on ranches is suitable for jaguars that loose their habitats elsewhere. The project must lead to improved livestock cum wildlife management because areas with poor cattle managment encourage jaguar predation.

References

Forest Ecology and Forest Management Group (FEM) (2009) Tree regeneration in Church forests of Ethiopia. http://www.fem.wur.nl/UK/newsagenda/news/church_forests.htm

Geiger R, Aron RH, Todhunter P (1995) The climate near the ground, 5th ed. Vieweg, Braunschweig/Wiesbaden, 528pp

Hall A, Sulaiman VR, Dhamankar M, Bezkorowajnyj P, Prasad L (2008) Reframing technical change: livestock fodder scarcity revisited as innovation capacity scarcity Part 1: a review of historical and recent experiences. United Nations University – Maastricht economic and social research and training centre on innovation and technology Working Paper 2008-002, 24pp. http://www.merit.unu.edu/publications/wppdf/2008/wp2008-002.pdf

Hilhorst T (2008) Local governance institutions for natural resource management in Mali, Burkina Faso and Niger. KIT Working Papers Series G1. KIT, Amsterdam, 25pp. http://www.kit.nl/net/KIT_Publicaties_output/ShowFile2.aspx?e=1445

Hudak M (2000) Commercial livestock production on federal public lands. Environmental destruction at taxpayer expense. http://www.mikehudak.com/Articles/ CommercialLivestock 000629.html

Miranda MS (2009) Ecovolunteer experience. Assisting in field research in the Jaguar predation on livestock research and conservation project. http://www.ecovolunteer. org/download/ docs/0008.pdf

Wassie Eshete A (2007) Ethiopian Church forests: opportunities and challenges for restoration. PhD thesis, Wageningen University, The Netherlands, 204pp

Wassie Eshete A, Sterck FJ, Teketay D, Bongers F (2009a) Tree regeneration in Church forests of Ethiopia: effects of microsites and management. Biotropica 41:110–119

Wassie Eshete A, Sterck FJ, Teketay D, Bongers F (2009b) Effects of livestock exclusion on tree regeneration in Church forests of Ethiopia. For Ecol Manag 257:765–772

III.4.1.(f) Development of Microclimate Modification Patterns in Forestry

Kees Stigter

Regeneration of species of trees in their own partial shade apart, forest trees start life in microclimates similar to those of herbaceous annuals but grow to be the tallest of all plants (Smith et al. 1994). This last mentioned fact makes that forests develop their own microclimates that get modified during this development. The structure of forest stands can range from that of scattered trees (e.g. Kainkwa and Stigter 1994; Boffa 1999) to multi-storied multi-purpose forest gardens (where forestry becomes agroforestry) and tropical forests (e.g. Baldy and Stigter 1997).

Most common, however, is an intermediate condition with in the end a single closed canopy above and an open space beneath (Smith et al. 1994), the crucial differences with the scattered trees ultimately being the closed canopy and a lower degree of openness below. Because of forest topsoil microclimates being immediately a consequence of the forest aerial microclimate in a way that is smoothed by the topsoil thermal and moisture conditions (e.g. Stigter 1994), we will limit ourselves here to the "above soil microclimates".

In a closed canopy one can not grow agricultural crops, but between scattered trees one can, because of these differences in microclimate. This is also why crops are grown together with young forest trees but no longer when they get older (e.g. Baldy and Stigter 1997). Forest microclimates differing from the bulk forest climate can only be found at forest edges and in clearings or natural openings in the forest, that have therefore got special attention in the forest (micro)climate literature (e.g. Geiger et al. 1995).

Knowledge of edge microclimate is important in forestry stand natural regeneration or artificial planting of new seedlings (Geiger et al. 1995) and so it is if edges are used for agricultural purposes. Important variations in radiation, wind and rain are occurring at the forest surface near the edges that can be exploited in forest culture (Michon 2005), whether this are an outer edge around a forest stand or inner edges of relatively small forest clearings/openings within the forests. Together with

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_52,

heights and densities of trees, the sizes of such edges/clearings/openings are most determining for the microclimate gradients in that environment.

Forest harvesting can increase solar radiation in a riparian zone as well as wind speed and exposure to air advected from clearings, typically causing increases in summertime air, soil, and stream temperatures and decreases in relative humidity (Moore et al. 2005). An interesting aspect is the radiation frost protection in forest clearings, seen as heterogeneous canopies with low sky view factors for the lower plants, of which the literature was recently reviewed in Winkel et al. (2009). Examples of microclimate gradients in forests responsible for gradients in damage under severe weather are given in Box III.4.7.

Most forest populations are engaged in low intensity shifting swidden agriculture. But such environments are vanishing with their populations or with their slash and burn technologies. Classical books are Kunstadter et al. (1978) on "farmers in the forest" in Thailand. However, increasing clearing size changed the land use patterns from those formerly based on small clearings, substantially impacting forest regeneration and watersheds in general (Thomas et al. 2003). We seem to have forgotten that all culture after the invention of agriculture has been conquered on the forest. One might say that every city, even the biggest metropolis, is an open space that has been enlarged beyond all proportions, while the forest itself is mostly gone (Gläntor 2009).

Box III.4.7 (Contributed by Kulasekaran Ramesh and Kees Stigter)

Although ice storms are only one of a number of common factors that affect the US eastern forests, the 2003 ice storm caused more damage than most typical ice storms. These natural and recurring events occur with varying degrees of intensity, duration, and frequency. An ice storm as a large-scale ecological disturbance that severely affected the Ironton Ranger District occurred during 2003. The storm produced widespread limb and bole breakage, blowdown, and bent trees (Muccio 2008). These damages are related to developed microclimates. Asymmetrical crowns and/or slender, weak stems aggrevate these problems (Smith et al. 1994).

Snow damage may occur when in a changing microclimate a certain snow load develops and is enough to break the tree. Snow accumulation is the highest during light winds and decreasing temperatures, but strong winds aggravate the bending. The size and form of snowflakes are most suitable for accumulating on trees at temperatures between $+1$ and $-3\,^{\circ}\mathrm{C}$. Moderate winds can also cause damage if trees are loaded by snow. Scots pine and Norway spruce have been found out to be more susceptible to wind damages in interaction with snow than birches. Critical combination of snow loading and wind speed increases when stems taper (Pellikka and Järvenpää 2003). Microclimates play a role in these phenomena.

References

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris, France; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Boffa J-M (1999) Agroforestry parklands in Sub-Saharan Africa. FAO Conservation Guide 34, Rome, 230pp

Geiger R, Aron RH, Todhunter P (1995) The climate near the ground, 5th ed. Vieweg, Braunschweig, 528pp

Gläntor (2009) Clearings in the forest. http://www.hellefors.se/kommun/glentor/

Kainkwa RMR, Stigter CJ (1994) Wind reduction downwind from a savannah woodland edge. Neth J Agric Sc 42:145–157

Kunstadter, P, Chapman EC, Sabhasri S (eds) (1978) Farmers in the forest: economic development and marginal agriculture in Northern Thailand. University Press of Hawaii, Honolulu, 402pp

Michon G (2005) Forest culture. The Overstory, Paper 158. PAR, Holualoa, USA. http://www.mail-archive.com/sustainablelorgbiofuel@sustainablelists.org/msg52658.html

Moore RD, Spittlehouse DL, Story A (2005) Riparian microclimate and stream temperature response to forest harvesting – a review. J Am Water Resour Assoc 41:813–834. http://www.for.gov.bc.ca/hre/pubs/pubs/1391.htm

Muccio D (2008) Meeting held on Wayne National Forest to discuss damage from 2003 ice storm. Northeastern Area News Notes, Feb 25. www.na.fs.fed.us/newsnotes/2008/feb/feb08.pdf

Pellikka P, Järvenpää E (2003) Forest stand characteristics and snow and wind induced forest damage in boreal forests. In: Ruck B, Kottmeier C, Mattheck C, Quine C, Wilhelm G (eds), Wind effects on trees. University of Karlsruhe, Karlsruhe, pp 269–276

Smith DH, Smith WH, Reifsnyder WE (1994) Silviculture, pests and disease, forest and wildland fires. Chapter 20 In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York, pp 210–219

Stigter CJ (1994) Management and manipulation of microclimate. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York, pp 273–284

Thomas D, Weyerhaeuser H, Saipathong P (2003) Improved tools for managing agroforestry landscapes in northern Thailand: pilot application of spatial analysis and negotiation support systems. In: Xu Jianchu, Mikesell S (eds) Landscapes of diversity: indigenous knowledge, sustainable livelihoods and resource governance in Montane Mainland Southeast Asia. Proceedings of the 3rd Symposium on MMSEA, Lijiang, 25–28 August 2002. Yunnan Science and Technology Press, Kunming, pp 381–400. http://www.worldagroforestrycentre.org/sea/Publications/files/paper/PP0147-05.PDF

Winkel T, Lhomme JP, Nina Laura JP, Alcon Mamani C, del Castillo C, Rocheteau A (2009) Assessing the protective effect of heterogeneous canopies against radiative frost: the case of the quinoa crop on the Andean Altiplano. Agric For Meteorol, 149:1759–1768

III.4.1.(g) Designs of (Changes in) Protection Measures Against Extreme Climate in Forestry

Dick Felch

Extreme climate in forestry is exemplified in Box III.4.8. The largest effects of future climatic variability or change on northwest forests in the USA are likely to arise from changes in fire frequency and fire severity. The past two decades demonstrated increasing burned areas in Canada, the western United States and Russia, because of both climatic conditions and other factors such as fuel conditions, ignition sources, land use change and variations in fire protection (Westerling et al. 2006; Gillet et al. 2004).

Box III.4.8

Extreme climate in forestry can take many forms. For example, extreme winds resulting in blowdown of vast areas of trees, drought and its impact on the occurrence and intensity of forest fires (Westerling et al. 2006) and the impact of extremes on insect and disease development (Alig et al. 2002). Many climate change studies support the conclusion that global warming would likely increase the frequency and intensity of such events. The actual time pattern of change will be complex, owing to lags between atmospheric changes, climate effects and biological responses. Economic impacts resulting from growth changes will be further delayed due to the length of forest rotations, generally two or more decades (Alig et al. 2002). The exact time period may vary depending on local area, but this would include protection related issues such as the buildup of disease and insect populations over a period of years, or the buildup of forest undergrowth and its impact on forest fire management.

Other regions demonstrated both increasing and decreasing fire activity (Mouillot and Field 2005; Bergeron et al. 2004; Girardin et al. 2004; Williams et al. 2001). There is general agreement amongst all these researchers that prolonged

D. Felch (✉)
National Weather Service, NOAA(retired), Chanhassen, MN, USA
e-mail: dickfmn@gmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_53,

snow-free periods and increasing frequency and intensity of droughts can be expected to elevate the frequency of forest fires in many regions. Such changes also demand changes in protection measures.

For many forest types, forest health protection questions are of great concern with pest and disease outbreaks as major sources of natural disturbance due to climate change. The effects vary from defoliation and growth loss, to timber damage, to massive forest diebacks. For example, in 1998–2002, 5 million hectares of forest (1.7% of the forest area) were adversely affected by insects in the United States and 14 million ha was affected in Canada (4.5%); the area annually damaged by insects in North America is 2.9% of the total forest area (FAO 2005). It is very likely that these natural disturbances will be altered by climate change and have an impact on forestry (Alig et al. 2002).

There is evidence that warmer temperatures have already shifted the habitats of some forest insects, e.g. the mountain pine beetle (Carroll et al. 2004). Other important forest insects, such as the gypsy moth, are more responsive to precipitation change. Climate change can dramatically shift the current boundaries of insects and pathogens and modify tree physiology and tree defense mechanisms. This asks for (changes in) protection measures.

A growing concern is that in the new habitats the insects may damage the tree species that presently cannot tolerate insect outbreaks. Under a very moderate 2 °C warming, for example the mountain pine beetle is likely to seriously threaten the Rocky Mountain whitebark pines, which provide food for many wildlife species (Logan and Powell 2001). Such a warming must be considered extreme climate in such a case and protection strategies will have to be developed, for example in the direction of biological control.

The FASOM (Food and Agriculture Sector Optimization Model) model suggests that several forms of adaptation (or protection) may be used in the forest sector, including changes in (a) land use choices, (b) timber management interests, (c) hardwood/softwood species mix, (d) timber growth and harvesting patterns within and between regions, (e) rotation ages and (f) consumer use of wood vs other products (FAO 2005).

In terms of future areas of study, work to simulate vegetation and product yields under climate change scenarios should be integrated with research to improve baseline estimates of carbon sequestration in forests (Alig et al. 2002).

References

Alig RJ, Adams DM, McCarl BA (2002) Projecting impacts of global climate change on the USA forest and agricultural sectors and carbon budgets. For Ecol Manag 169:3–14

Bergeron Y, Flanigan M, Gauthier S, LeDuc A, Lefort P (2004) Past, current and future fire frequency in the Canadian Boreal forest and implications for sustainable forest management. Ambio 6:356–360

Carroll AL, Taylor SW, Regniere J, Safranyik L (2004) Effects of climate change on range expansion by the mountain pine beetle in British Columbia CA. In: Shore TL, Brooks JE, Stone JE (eds) Mountain Pine Beetle Symposium: Challenges and Solutions, Kelowna, 30–31 October 2003. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre Information Report BC-X-399, pp 223–232

FAO (2005) Global forest resources assessment 2005. Food and Agriculture Organization Forestry Paper 147, Rome, 320 pp. http://www.fao.org/DOCREP/008/a0400e/a0400e00.htm

Gillet NP, Weaver AJ, Zweirs FW, Flanigan MD (2004) Detecting the effect of climate change on Canadian forest fires. Geophys Res Let 31:L18211

Girardin, MP, Flanigan MD, Wotton BM, Bergeron Y (2004) Trends and periodicities in the Canadian Drought Code and their relationship with atmospheric circulation for the southern Canadian boreal forest. Can J For Res 34:103–119

Logan JA, Powell JA (2001) Ghost forests, global warming, and the Mountain Pine Beetle (*Coleoptera: Scolytidae*). Am Entomol 4:160–173

Mouillot F, Field CB (2005) Fire history and the global carbon budget: a $1° \times 1°$ fire history reconstruction for the 20th century. Global Change Biol 11:398–420

Westerling, AL, Hildago HG, Cayan DR, Swetnam TW (2006) Warming and early springs increase western US forest fire activity. Science 313:940–943

Williams AAJ, Karoly DJ, Tapper N (2001) The sensitivity of Australian fire danger to climate change. Clim Change 49:171–191

III.4.2 Coping with Climate Variability and Climate Change

III.4.2.(i) Improving the Issuing, Absorption and Use of Climate Forecast Information in Forestry

H.P. Das

Climate forecast information needs of forest managers are based on issues and problems of forest management and related ecosystem management. In order to provide quality service to forest managers, it is essential to identify and understand those issues and problems which require meteorological or climatological information. Knowing how the information is used is crucial to providing a quality service for effective forest management. As problems and issues (Fosberg 1987, 1990), we mostly consider catastrophes such as forest fires, wind storms and floods; climate change; chronic air pollution threats; insect and disease outbreaks; and for example issues like economic development of forest resources and preservation of ecosystems. Each has its own meteorological and climatological forecast needs at particular time and space scales.

One must first look at who makes a policy or managerial decision and what information is needed to make that decision or policy (Bernabo and Ellington 1992). The examples mentioned in the previous paragraph give us a meteorological scale of hours to days for forest fires, floods and wind storms; decades to years for insects and diseases or chronic air pollution; years to a century for climate change, to show impact on forests; and a continuum of time and space scales for economic sustainability. Understanding the processes of how decisions are made and how policies are established is equally important. There are numerous factors which influence any decision or policy making. These range from goals of the farmer in local land use management to strategic goals established by international treaties and agreements.

Knowing who makes the decisions or how policies are established determines to whom and where the climate forecast information should be directed. There may be multiple users requiring somewhat different information. For example, forecasts of danger from avalanches has multiple users: the local land manager may need to consider making an administrative decision of whether or not to restrict entry

H.P. Das (✉)
Retired from Indian Meteorological Department, Pune, India
e-mail: hpd_ag@rediffmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_54,

into a danger area; people who use that area, either for recreational or commercial use, will need to know of the danger and of the closure; and in case there are public transportation routes through the area, users of those routes will also be impacted (Fosberg 1995). Post processing of forecasts and adding value to the forecast through understanding of forest/weather relationships is routine for forest managers. In an avalanche danger example, the land manager has knowledge of the snow pack condition, the terrain, and an understanding of what snowfall and temperature changes will result in avalanches. It is then essential to understand how information is processed and how value is added to the forecast information by resource managers.

Technical assistance comes from progress in methodologies (see also Box III.4.9). In a simple example, forest fire danger is determined by precipitation, temperature, humidity and wind speed. These meteorological elements combine in a non-linear relationship with the forest vegetation to determine rate of spread of forest fires and intensity of the fire. Value is added to the meteorological information through understanding the quantitative relationships mathematically. The use of seasonal climate data of certain specific forest areas prone to forest fires could be used by the forest managers to enable taking certain fire prevention measures or mounting fire operation measures in advance to mitigate possible damages (Stefanski 2004; Nunez 2005; Das 2005).

Box III.4.9

The ability to predict El Nino Southern Oscillation (ENSO) would provide lead time to forest managers in the USA in preparing for years of high fire activity, and other drought preparedness measures. ENSO, for example, can result in increased chances of droughts in some regions of the US and floods in other regions, and as a result, affect wildfires (Qu and Wolf 2003). During the El Nino phase, the southwestern US typically experiences enhanced winter but slightly decreased summer precipitation, but the opposite is true of the La Nina phase. Overall, El Nino episodes tend to be associated with wetter years and La Nina episodes with drier years (Betancourt et al. 1993). ENSO can also contribute to the inter-annual variability of vegetation in North America (Bachelet et al. 2001). In South America also, Nepstad et al. (2004) observed that during the 2001 ENSO period, approximately one third of Amazon forests became susceptible to fire.

Satellite remote sensing has also great potential to provide information for calculation of seasonal fire danger. The fuel moisture detected by satellite remote sensing is mostly the moisture of live fuel, which predominantly represents long-lag moisture (e.g. 1,000 h fuel moisture), a determining factor of seasonal fire danger. Thus it is possible to develop a capacity to assess the seasonal fire danger using remote sensing of fuel moisture and other products.

These products are limited by a spatial resolution of 1 km or more and thus are generally only representative at meso or synoptic scale (Riebau and Qu 2005). Satellite sensors are also capable of discerning physiological changes within plant species in the forest through spectral radiance measurements and manipulation of this information into drought preparedness measures (Das 2004). Forest maps on the basis of satellite images are a basic information source for habitat modeling, prediction and mapping of forest insect infestations, and plant and animal biodiversity assessment (Roy 2004).

On the basis of the fire/weather relationship, a system of fire danger rating has been evolved to guide the fire management people in their day to day activity and also to provide a basis for comparing weather and fire behavior throughout the nation or region. Forest fire danger rating in Canada and a universal system of fire danger rating along with fire weather forecasting in the USA are providing valuable information to mitigate possible damage due to forest fire.

Routine processing of meteorological data in Fire Danger Rating Systems (FDRSs) provide forest managers with an estimate of the next day forest fire suppression needs by adding value to the meteorological forecasts (Fosberg et al. 1996). The value added here is to relate weather to forest fire behavior, what level of fire suppression is required, and where it is required. FDRS early warning information is often enhanced with satellite data such as hot spots for early fire detection and spectral data on land cover and fuel conditions (Brady et al. 2007). Normally these systems provide a 4–6 h early warning of the highest fire danger for any particular day that the weather data are supplied.

The other manner in which value can be added is through risk assessment and its mode of transfer (see Box III.4.10). The next step is then that there is a need for continuing dialogue between the NMHS and the resource manager on the issues and problems, how value is added to the services, what the base is, what the technological capabilities of the manager are, and how the information is used in decision support systems. All these steps mentioned above are intended to provide a framework for or guidelines to NMHSs for determining both current and future needs of forest managers. It is equally important that forest managers must also understand the capabilities and limitations of forecast information provided by NMHSs.

Box III.4.10

Disturbance in forest ecosystems is tightly interconnected as is forest biome and forest growth (Fosberg and Stock 1992). Variances from this classic picture are important in the decision and policy arena: for example, regional variations in weather will result in changes in forest fire severity. Forest fire suppression forces (number of personnel, type and quantity of equipment) are determined by past requirements and expected fire severity. In this case, concern is not with the average or statistically expected values, but with the extreme event. Since it is economically impractical to be prepared for the worst possible case, a level of fire severity of the highest 10% is typically chosen as the level of maximum suppression force to be established.

Existing forces then should be able to suppress 90% of the forest fires with minimal impact on life, property or resources. If weather produces fire severity which exceeds this worst 10% level in one region, plans are made to move additional forces into that region from regions of low fire severity. Because notification and staging requires lead times, 5 to 10 days forecasts are of importance. Costs of moving large numbers of personnel and equipment are high. Thus the probabilities of dangerous fire conditions beyond the capabilities of the local forces in the impacted area are extremely useful (Fosberg 1995).

If there are regional shifts in the severity as a result of global climate change, particularly at the extreme end (Fosberg et al. 1992, 1996), then there will be a need to make long term investment in adapting local or regional fire suppression forces to meet those future needs. This may require permanently shifting suppression forces, or adding forces, or reducing forces. These strategic decisions can involve a large economic outlay (Cooper 1994; Fosberg et al. 1996).

It is also important to consider how the information is conveyed to the user and in what format that information is presented. Information delivery by telephone, facsimile, or internet communication offer great opportunity (Motha 2001; Das 2004). A complete transfer of all sorts of climate information is not only unfeasible, but will likely result in no information being used. Basically, the decision maker can not work with an overload of information as he must consider information from non-meteorological sources as well. In many cases, the non-meteorological information will carry higher weight in the decision process, even if the issue or problem is strongly controlled by meteorological factors.

For example, though bushfires in many parts of the world are controlled by hot and dry wind, the information required from the NMHS by decision makers attempting to control those fires is whether the conditions will continue or abate. Under these conditions, the critical climate information is based on where fire suppression forces are located, where they are needed, and how to move these forces quickly and efficiently. Attention needs to be given to what is critical information in the decision process, and what information the NMHS needs for internal use to develop the critical information passed on to the forest manager.

References

Bachelet D, Neilson RP, Leniham JM, Drapek RJ (2001) Climate change effects on vegetation distribution and carbon in the United States. Ecosyst 4:164–185

Bernabo JC, Ellington DD (1992) Joint climate project to address decision makers' uncertainties. Report No. TR-100772. Electric Power Research Institute, Pleasant Hill, California, 86pp

Betancourt JL, Pierson EA, Rylander KA, Fairchild-Parks JA, Dean JS (1993) Influence of history and climate on New Mexico Pinyon-Juniper woodlands. In: Aldon EF, Shaw DW (eds), Managing Pinyon-Juniper ecosystems for sustainability and social needs. USDA Forest Service, Rock Mountain Forest and Rangeland Experiment Station, Gen. Tech. Rep. RM-236, Fort Collins, Colorado, pp 42–62

Brady AB, de Groot WJ, Goldammer JG, Keenan T, Lynham TJ, Justice CO, Csiszar IA, O'Laughlin K (2007) Developing a global early warning system for wildland fire. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in Agriculture. Springer, Berlin/Heidelberg/New York pp 355–375

Cooper W (1994) Risk assessment requirements. Arct Res 8:112–115

Das HP (2004) Satellite-based agro-advisory service. In: Sivakumar MVK, Roy PS, Harmsen K, Saha SK (eds) Satellite remote sensing and GIS applications in agricultural meteorology. AGM-8, WMO/TD 1182, Geneva, pp 347–360

Das HP (2005) Agrometeorological impact assessment of natural disasters and extreme events and agricultural strategies adopted in areas with high weather risks. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 93–118

Fosberg MA (1987) Forest forecasting. Proceedings of the Conference on Wildland Fire 2000, University of California Press, Berkeley, pp 105–114

Fosberg MA (1990) Global change – a challenge to modeling. In: Dixon R (ed) Forest growth: process modeling of response to environmental stress. Timber Press, Portland, pp 3–7

Fosberg MA (1995) Meteorological needs for temperate and boreal forest management. CAgM Report No. 64, WMO/TD 728, Geneva, pp 1–13

Fosberg MA, Stock BJ (1992) Global change and boreal forest ecosystems. American Society of photogrammetry and remote sensing, Vol. 5. Resource Technology, pp 164–176

Fosberg MA, Mearns LO, Price C (1992) Climate change-fire interactions at the global scale: predictions and limitations of methods. In: Crutzen P, Goldammer JG (eds) Dahlem conference of fire in the environment: The ecological, climatic and chemical importance of burning in wildland and rural landscapes. Wiley, New York, etc, pp 345–356

Fosberg MA, Stock BJ, Lynham TJ (1996) Risk analysis in strategic planning: fire and climate change in the boreal forest. In: Goldammer JG, Furyaev VV (eds) Fire in ecosystems of boreal Eurasia. Forestry Sciences, Vol. 48. Kluwer, Dordrecht, etc, pp 494–505

Motha RP (2001) Agrometeorological bulletins – how can we improve them? Proceedings of the Inter-Region Workshop, Bridgetown, pp 13–24

Nepstad DC, Lefebvre PA, da Silva ED, Tomasella J, Schlesinger P, Solorzano L, Moutinho P, Ray D, Banito JG (2004) Amazon drought and its application for forest flammability and tree growth: a basin-wide analysis. Glob Change Biol 10:704–717

Nunez L (2005) Tools for forecasting or warning as well as hazard assessment to reduce impact of natural disasters on agriculture, forestry and fisheries. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin, etc, pp 71–92

Qu J, Wolf H (2003) Wildfire behaviour science and modeling strategic planning. Presentation for USDA/FS R&D, National fire plan, January 16–17, New Orleans, 20pp

Riebau AR, Qu JJ (2005) Application of remote sensing and GIS for analysis of forest fire risk and assessment of forest degradation. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 335–350

Roy PS (2004) Forest fire and degradation assessment using satellite remote sensing and geographic information systems. In: Sivakumar MVK, Roy PS, Harmsen K, Saha SK (eds) Satellite remote sensing and GIS applications in agricultural meteorology. AGM-8, WMO/TD 1182, Geneva, pp 361–400

Stefanski R (2004) Impact of agrometeorological applications for sustainable management of forestry. In: The impacts of agrometeorological applications for sustainable management of farming, forestry and livestock systems. CAgM Report 92, WMO/TD 1175, Geneva, pp 29–55

III.4.2.(ii) Sustainable Development and Use of Forest Ecosystems

Al Riebau

The term sustainable development is often used but there are significant, if subtle, differences in what this term means to people. See also Chap. IV.3. This is especially true in forest management. For simplicity, three different viewpoints are presented to illustrate how understandings of sustainable forests differ.

For some, a sustainable forest ecosystem is one which allows a continuous production for some time in the distant future of wood and/or fibre and/or food and/or fuels for use in the home or in centralised electricity or heat generation (Diamond 2005). For others, a sustainable forest is one that supplies a whole spectrum of ecosystem services now and into that same distant future. Such services are often listed as including wildlife habitat, microhabitats for plant biodiversity, water storage and regulation, soil health, carbon sequestration, and many others (DAFF 2009). The view of a sustainable forest as a continuous factory for materials production and the view of a sustainable forest as a foundation for ecosystem services can be, and are often sought to be, harmonised by forest managers.

A third viewpoint on sustainable forests is an emerging non-anthropocentric view, one in which a sustainable forest is a forest that exists indefinitely for purposes of preservation of the forest ecosystem in its own right, beyond any human benefits, values or even valuation. This view is often associated with protected forest areas, or wilderness reserves. It often has been associated with a type of human valuation (which is itself an admitted paradox) of an independent "right of nature" to preserve wilderness character or forest spirit (Stokes 1999). In this view, mankind is transient and forest ecosystems are thought to have an intrinsic value, even if humankind should entirely perish. Although this viewpoint can be harmonised with the two presented above in theory, it has often not be easy to accomplish this in practice (Watson 2004).

For those living in developed countries deeply concerned with the intrinsic values of wilderness character or forest spirit, the production of any products from the forest can be anathema and is, by definition, entirely at odds with forest ecosystem

A. Riebau (✉)
Retired from USDA Forest Service Research and Development, Nine Points South Technical PTY LTD, Clarkson, WA, Australia
e-mail: ariebau@ninepointsouth.com.au

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_55,

sustainability. Indeed, the creation of parks, or what is called in North America preserves, to protect forests have sometimes displaced indigenous populations in Africa, Asia, and South America, people often credited with living a most sustainable lifestyle. For those deeply concerned with the production of materials from forests and the very real needs of the indigenous human populations relying on such products, the view of preservation of wilderness character can be understood as naive and pointless. People holding the view of a sustainable forest as an eternal fountain for ecosystem services sometime perhaps feel trapped in the middle. Real conflicts have arisen between all three viewpoints which were very simplistically portrayed here (Schuster et al. 2007; Stankey 1971). None of these simplistic viewpoints may provide a solid definition of sustainability independently.

A synergism between the above three viewpoints must be found as climates shift and variability in climates increases. To accomplish this, an understanding of just what is a forest ecosystem must be discussed as the term has a multitude of meanings. Adapted from Ray Clapham's 1930s terminology, an ecosystem is a system that includes all living organisms (biotic factors) in an area as well as its physical environment (abiotic factors) functioning together as a unit (Biology On-Line 2009). This author likes to think that an ecosystem could be an entire rain forest, covering a geographical area larger than many nations, or that it could be a puddle or a backyard garden. The term ecosystem itself is rather imprecise, which causes the idea of sustaining forest ecosystems to also be imprecise. Approaches to find such synergism might include:

- development without growth in consumption of forest resources or without throughput beyond environmental carrying capacity;
- a goal of non-decreasing per capita (as related to persons and forest species) well-being across generations;
- setting and maintaining the amount of forest ecosystem resources consumption that can be continued indefinitely without degrading capital stocks – including natural resources "capital stocks" such as wood, fibre, water, soils, biodiversity and more (adapted from Goodland 1992).

What is clear from this imprecision in what an ecosystem comprises is that differing groups can see a forest ecosystem as large or small, including human factors or not, and being at the same time stable or unstable. This lack of consensus of understanding is still a major issue for forest managers seeking a management paradigm that achieves sustainability (MacCleery 1994). Ultimately the viewpoints of forest ecosystems as materials production sites, ecosystem services platforms, and places of spirit can form a long-term partnership under a principle of sustainability.

Sustainability can bring this synergy through a recognition of the long-term nature of the problem, brought to the table by the products viewpoint, the appreciation of the scientific complexities of the issues championed by the ecosystem services advocates, and the supra-human ethical dimensions of sustainability elaborated by those advocating forest ecosystem intrinsic values. The great threats to this hopeful synergism based on a recognized shared need for sustainability are factors and forces of scales larger than the forest ecosystems being managed. Climate variability and change are two such factors and forces.

Climate change is commonly understood to be continental scale shifts in yearly average weather patterns and ranges, precipitated by an increase in human-caused green house gases, most often visualised as potentially being highly adverse to peoples' desires or activities (IPCC 2001). Naturally, such large scale shifts are anticipated with apprehension by people at regional or local scales, causing concerns for livelihood, health, and happiness. Although pockets of scepticism remain, in the past decade the scientific debate about the potential of green house gas emissions to change earth's climate has fundamentally ended. However, political action on a planetary scale has not been such as to alleviate apprehension over adverse consequences.

Human exacerbated climate variability, the shorter-term (less than a decade or even annual) anthropogenically influenced increase in fluctuations in weather patterns at continental or regional scales, is potentially one of the most devastating of climate change phenomena. This is especially so when climate variability results in increasing extreme events in intensity and duration. For forest ecosystems, a shift in the overall climate of a continent will mean (as has been shown objectively by a number of studies, see in particular Sect. III.4.5.(α)) that whole forest ecosystems will become unsuited or "mal-adapted" to land areas they now occupy. In such instances, no human intervention could conceivably force such a forest ecosystem to be sustainable.

An example of such a situation may be the change in cold degree days combined with longer growing seasons exacerbating bark beetle infestations in the US state of Colorado, to the point where Rocky Mountain alpine forest ecosystems are severely jeopardised by wildfires (Westerling et al. 2006). In recent years, Colorado's forests have experienced several large-scale insect infestations, from ips beetles in the pinyon forests of southwestern and southeastern Colorado to mountain pine beetles in northern lodgepole pine forests. In both cases, the infestations have resulted or will result in tree mortality rates that exceed 90%. In addition, Sudden Aspen Decline (SAD) more than doubled in Colorado from 2006 to 2007, increasing from 139,000 to 334,000 acres (State Government of Colorado 2007).

Interesting too is that issues such as acid rain may re-emerge as climates change. Research in Welsh streams has shown that forest ecosystem streams have lost buffering capacity due to increases in winter rainfall, thus once more making them more susceptible to acidification (Lepori et al. 2003). As will be examined in Sect. III.4.2.(iii), climate change and variability can also increase both the occurrence and, more importantly, the severity, of forest fires.

Sustainability is more than just preservation. It is humankind's highest aspiration for the active state of forest ecosystems. Although climate change mitigation offers economic opportunities for advancing forest ecosystem sustainability (see for example Box III.4.11), climate change itself is perhaps the largest threat to forest ecosystems (Carrillo-Rubio 2009). Past concepts of the forest ecosystem may need to be expanded or modified if sustainability is to be achieved under regimes of large scale climate change resulting in landscape level systemic cascades of maladapted forest biomes (Jirka et al 2007). Some approaches suggested by the present author are:

- Development of forest databases beyond those used for resources inventory, with such databases raised to an international standard that would allow resource, biodiversity, habitat, pests, and microclimate information sharing across national boundaries.
- More training for foresters in climate and climate related ecology, with a complementary increase in bioclimatology expertise in forestry organizations at all levels of governments (national, state, provincial, territory, region, etc.).
- More and more widespread use of data from earth observation remote sensing, with an eye to both mapping forest ecosystems and designing sustainability stratagems before potential climate change is realised.
- Furthering on-the-ground monitoring programs which collect data to assess and understand the effects of climate change and other disturbance factors as synergistic effects to forest ecosystems. The International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests operating under the UNECE Convention on Long-range Transboundary Air Pollution (European ICP Forests) programme is an example to consider (ICP Forests 2009).

Box III.4.11

Climate change and climate variability also offer an economic opportunity to sequester carbon. This may be an exceptional opportunity for managers of tropical forests (see also Sect. III.4.5.(ε)). Forestry activities have the economic potential to offset 2–4% of projected CO2 emissions by 2030, with tropical regions accounting for nearly two thirds of the total offset (Canadell and Raupach 2008). Such carbon off-set opportunity may not be universally true for all forests. For example, forests also affect biophysical properties of the land surface, such as sunlight reflectivity and evaporation. Climate models suggest that large reforestation programs in the boreal (colder) regions of the word could have limited benefits due to the replacement of large areas of reflective snow with dark forest canopies (ICFPA 2008).

However, forest products themselves can sequester carbon in the form of durable wood products that can be recycled for other uses. Consumers of forest products can support sustainable forests by preferential purchasing of labeled products by groups such as the Forest Stewardship Council (FSC). Products carrying the FSC label are independently certified to assure consumers that they come from forests that are managed to meet the social, economic and ecological needs of present and future generations (FSC 2009). Such international programs have proven effectual in education and management of forests (Simula et al. 2001).

References

Biology On-Line (2009) Dictionary. Ecosystem. Definition. Biology On-Line, all rights reserved. http://www.biology-online.org/dictionary/Ecosystem

Canadell P, Raupach M (2008) Tropical forest sustainability: a climate change boon. CSIRO Media Release, Clayton South, Australia. http://www.csiro.au/csiro

Carrillo-Rubio L (2009) Beetle-Battle: A threat to the world's forests aggravated by climate change. Climate Institute, Washington. http://www.climate.org/topics/ecosystems/beetle-battle.html

DAFF (2009) Australia's sustainable forest management. Department of Agriculture, Fisheries and Forestry. Canberra. http://www.daffa.gov.au/forestry/national/forest-mgnt

Diamond J (2005) Collapse: how societies choose to fail or succeed. Viking/Penguin, New York, 592pp

FSC (2009) About FSC. Forest stewardship council. Bonn, Germany. http://www.fsc.org/about-fsc.html

Goodland R (1992) The case that the world has reached its limits. In: Goodland R, Daly HE, El Serafy S (eds) Population, technology and lifestyle: the transition to sustainability. Island Press, Washington, pp 3–22

ICFPA (2008) Forest products industry essential to climate change. International Council of Forest and Paper Associations. Brussels, etc. http://www.icfpa.org/issues_statements/statements/theForestProductsIndustryessentialtoClimateChange.php

ICP Forests (2009) The international co-operative programme on assessment and monitoring of air pollution effects on forests. Hamburg, Germany. http://www.icp-forests.org/

IPCC (2001) Climate change 2001: the scientific basis. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, Van der Linden PJ, Dai X, Maskell K, Johnson CA (eds) A contribution of working group I to the third assessment report of the Intergovernmental panel on climate change. Cambridge University Press, Cambridge, 94pp. http://chaser.env.nagoya-u.ac.jp/~kengo/lec/IPCC_TAR-FRONT.pdf

Jirka S, McDonald AJ, Johnson MS, Feldpausch TR, Couto EG, Riha S (2007) Relationships between soil hydrology and forest structure and composition in the southern Brazilian Amazon. J Vegetat Sci 18:183–194

Lepori F, Barbieri A, Ormerod SJ (2003). Causes of episodic acidification in alpine streams. Freshwater Biol 48:175–189

MacCleery D (1994) Reflections on "A definition of sustainability for ecosystem management" by Iverson D, Cornett Z. US forest service position paper. Eco-Watch 7/20/94. http://www.fs.fed.us/eco/eco-watch/ew940720.htm

Schuster RM, Cole J, Hall T, Baker J, Oreske R (2007) Appraisal of and response to social conditions in the great gulf wilderness: relationships among perceived crowding, rationalization, product shift, satisfaction, and future behavioral intentions. In: Burns R, Robinson K (comps) Proceedings of the 2006 Northeastern Recreation Research Symposium, Bolton Landing, USDA FS Gen. Tech. Rep. NRS-P-14:488–496

Simula M, Rametsteiner E, Blåsten A, Green T, Pajari B (eds) (2001) Forest certification: forging novel incentives for the environment and sustainable forest management. Proceedings of the International Workshop. Brussels, European Forestry Institute, Brussels, 168pp. http://www.efi.int/portal/virtual_library/publications/proceedings/43/

Stankey GH (1971) Wilderness: carrying capacity and quality. Naturalist 22(3):7–13

State Government of Colorado (2007) Colorado climate action plan: a strategy to address global warming. Colorado State, Denver, 36pp. http://www.colorado.gov/energy/in/uploaded_pdf/ColoradoClimateActionPlan_001.pdf

Stokes J (1999) Wilderness management priorities in a changing political environment. Int J Wildern 5(1):4–8

Watson A (2004) Human relationships with wilderness: the fundamental definition of wilderness character. Int J Wildern 10(3):4–7

Westerling AL, Hidalgo HG, Cayan DR, Swetnam TW (2006) Warming and earlier spring increase western U.S. forest wildfire activity. Science 313:940–943

III.4.2.(iii) Detection of and Awareness on Increasing Climate Variability and the Elevated Risk to Forestry

Al Riebau

The conclusion in the introduction to PART III of this book, that the potential for world-wide economic and social disruption is possibly enormous (NOAA 2007) is certainly a disconcerting prediction for agriculture and forestry. It undermines what farmers and foresters perceive as the natural state of the world. Not only will agriculture become less predictable but markets will also become less predictable. Historical examples of natural climate variability demonstrate that the consequences of climate variability can be both beneficial or dire (see Box III.4.12).

Box III.4.12

Before the Little Ice Age, Europe and the entire northern hemisphere went through a short period of warm summers and mild winters (Medieval Warm Period). This period was followed by a period of oscillating temperature minima lasting almost 400 years. It is generally agreed that there were three minima, beginning about 1650, about 1770, and 1850, each separated by slightly warmer intervals (Lamb 1977). This period of climate variability had great impacts on the medieval world, and played a major role in the initial success and then failure of Nordic colonies in Iceland and Greenland, both of which heavily relied upon a predictable mild climate for agriculture, forest products and trade (Diamond 2005).

As a current example, there have been dramatic changes over the last decade in the characteristics of hurricane activity over the Atlantic, with associated impacts, also for forestry, over North America (NASA 2007a, b). It is currently an unresolved issue whether these changing hurricane characteristics are due to human-induced climate change or are attributable to natural variability – or some combination

A. Riebau (✉)
Retired from USDA Forest Service Research and Development, Nine Points South Technical PTY LTD, Clarkson, WA, Australia
e-mail: ariebau@ninepointsouth.com.au

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_56,

thereof. The answer to this question has major implications for understanding the likely characteristics of future Atlantic hurricane activity (NCAR 2005).

Climate variability is so important that its prediction, and prediction of its impacts, is becoming one of the most important issues of climate change science. Some nations, such as the United States, are funding more research on the issue (USCCSP 2009), but many see research funding levels to be inadequate to the scale of the problem (ABC Radio 2008; Columbia University's Mailman School of Public Health 2009).

Due to warming temperatures in northern latitudes, areas where forest can grow (the tree line) may move north. Warmer temperatures are also expected to expand the ranges and enhance the survival rates of forest pests such as the spruce budworm and the mountain pine beetle: 80% of British Columbia's mature pine forest could this way be lost in the next 10 years (David Suzuki Organization 2009).

In the UK, "top-dying" of norway spruce is likely to increase in England and eastern Scotland; norway spruce could cease to be a productive species over much of England. Defects in coniferous timber due to drought crack are also likely to increase in England. Increased winter rainfall may raise water tables enough to kill roots, thereby reducing effective rooting depth and making trees more vulnerable to summer droughts (Forestry Commission 2002).

Although many other examples can be cited, few are as compelling as forest fires. Almost seven times more United States forested federal land burned during the 1987–2003 period than during the prior 17 years. In addition, large fires occurred about four times more often during the latter period (University of Arizona 2006). The new finding points to climate change, not fire suppression policies and forest fuel accumulation, as the primary driver of recent increases in large forest fires (Westerling et al. 2006).

More importantly, the intensity and spatial extent of forest fires is radically changing (Kasischke and Turetsky 2006; WRI 2007). As climate variability increases, the term "megafires" is now becoming used worldwide to describe huge, multi-week, ultra-high intensity forest fires (Taylor 2007). Such fires rage over many miles at 1,000 °C temperatures and create their own weather, even triggering their own localized fire "tornadoes" (Battaglia et al. 2000; Pyne 2006). Rapidly increasing in number, they are often unquenchable by any human efforts, burning unchecked until they reach coasts or are put out by heavy rainfall (Hagens 2008). In the summer of 2007, as record heat waves hit much of southern Europe, more than 1.9 million acres went up in smoke, ravaging Greece and killing at least 63 people and charring 482,000 acres of land (Lean 2007).

The early detection of conditions that contribute to megafires is important not only for protection of life and property, but also for air quality management. Megafire events have caused smoke incidents in Moscow, Washington (DC), and other world cities, sometimes exceeding air quality standards for particulates and ozone (Chubarova et al. 2007, Fox et al. 2007). Boreal megafires, driven by a changing climate, have a high potential to cause major air pollution episodes in the megacities of the northern hemisphere.

References

ABC Radio (2008) Australian government urged to fund research into climate change. SomeBodyCare. Registration necessary. http://www.radioaustralia.net.au/news/stories/200807/s2309000.htm?tab=latest and http://prc.somebodycare.com/showthread.php?t=638

Battaglia F, McGrattan KB, Rehm RG, Baum HR (2000) Simulating fire whirls. Comb Theor Model 4:123–138

Chubarova NY, Prilepsky NG, Rublev AN, Riebau AR (2007) The 2002 mega-fire event in Central Russia: meteorology, optical properties of the atmosphere, air quality, and unexpected consequences. In: Bytnerowicz A, Arbaugh MJ, Riebau AR, Anderson C (eds) Wildland fire and air pollution. Elservier, Amsterdam, pp 247–264

Columbia University's Mailman School of Public Health (2009). Federal funding gap cited for research on human health impacts due to climate change. ScienceDaily of 26 March. http://74.125.77.132/search?q=cache:JIvZkssJ4RUJ:www.sciencedaily.com/releases/2009/03/090326150554.htm and http://www.sciencedaily.com/releases/2009/03/090326150554.htm &cd=1&hl=nl&ct=clnk&gl=nl

David Suzuki Organization (2009) Solving global warming. Impacts: forest impacts. David Suzuki Foundation, Vancouver, Canada. http://www.davidsuzuki.org/Climate_Change/Impacts/Forest_Impacts.asp

Diamond J (2005) Collapse: how societies choose to fail or succeed. Viking/Penguin, New York, 592pp

Forestry Commission (2002) Climate change: impacts on UK forests. Forestry commission bulletin 125. Forestry Research, Farnham, Surrey, UK, etc. http://www.forestresearch.gov.uk/website/forestresearch.nsf/ByUnique/INFD-5ZYHMC

Fox D, Ames R, Schichtel B, Malm W, Riebau AR (2007) Effects of forest fires on visibility and air quality. In: Bytnerowicz A, Arbaugh MJ, Riebau AR, Anderson C (eds) Wildland fire and air pollution. Elservier, Amsterdam, pp 171–196

Hagens N (2008) Fire and rain: the consequences of changing climate on rainfall, wildfire and agriculture. The oil drum. February 21. Institute for the Study of Energy and Our Future, Fort Collins, Colorado. http://www.theoildrum.com/node/3652

Kasischke ES, Turetsky MR (2006) Recent changes in the fire regime across the North American boreal region-spatial and temporal patterns of burning across Canada and Alaska. Geophys Res Lett 16:33

Lamb HH (1977) Climate: present, past and future. In: Climatic History and the Future, Vol. 2. Methuen, London. 837pp

Lean G (2007) More "Megafires" to come, say scientists. The Independent/UK of Sunday 2 September. http://www.commondreams.org/archive/2007/09/02/3570

NASA (2007a) Frequency of Atlantic hurricanes doubled over the last century; climatef change suspected. Earth Observatory. NASA Press Release. http://earthobservatory.nasa.gov/Newsroom/view.php?old=2007072925417

NASA (2007b) Hurricane turns forest from sink to source for carbon. Rising Tide. Confronting the root causes of Climate Change. NASA Goddard Space Flight Center, Greenbelt, Maryland. http://www.risingtidenorthamerica.org/wordpress/2007/11/15/hurricane-turns-forest-from-sink-to-source-for-carbon/

NCAR (2005) Hurricanes are getting stronger, study says. UCAR News release. National Center for Atmospheric Research. Boulder, Colorado. http://www. climatechange.com.au/2005/09/17/hurricanes-are-getting-stronger-study-says/

NOAA (2007) Observing climate variability and change. NOAA Research. Office of Oceanic and Atmospheric Research, Silverspring, Maryland. http://www.oar.noaa.gov/climate/t_observing.html

Pyne SJ (2006) Big burns, then and now. www.public.asu.edu/~spyne/BIGBURN.pdf (No further indications)

Taylor R (2007) World faces megafire threat – Australian expert. Reuters AlertNet of Monday 5 February. http://www.alertnet.org/thenews/newsdesk/SYD292002.htm

University of Arizona (2006) More large forest fires linked to climate change. ScienceDaily of 10 July. http://74.125.77.132/search?q=cache:qi1VWVfPufcJ:www.sciencedaily.com/releases/2006/07/060710084004.htm and http://www.sciencedaily.com/releases/2006/07/060710084004.htm&cd=1&hl=nl&ct=clnk&gl=nl

USCCSP (2009) CCSP annual report to congress: our changing planet CCSP-8. US Climate Change Science Programme, Washington. http://www.climatescience.gov/infosheets/ccsp-8/#funding

Westerling AL, Hidalgo HG, Cayan DR, Swetnam TW (2006) Warming and earlier spring increase western USA forest wildfire activity. Science 313:940–943

WRI (2007) Climate change increasing intensity, extent of wildfire. World Resources Institute. EarthTrends, Environmental Information. Submitted by Crystal Davis. http://earthtrends.wri.org/updates/node/203

III.4.2.(iv) (Changes in) Adaptation Strategies to Climate Change in Forestry

Al Riebau

A consensus on forestry and climate change is worded in Box III.4.13. Many reports link increased forest mortality to various combinations of notable dry and/or hot conditions, such as drought in the tropics from severe El Niño events in 1988 and 1997–1998, the persistent warming and widespread drought over much of western North America since the 1990s, and the extreme heat wave and drought of summer 2003 in western Europe (Allen 2009). There are three possible approaches for adapting forests to climate change: no intervention, reactive adaptation and planned adaptation (preparedness strategies, see Sect. III.4.1.(c)). Unfortunately, most have applied the first category of action or at best the second category (Bernier and Schoene 2009).

Box III.4.13

Adapting forestry to a changing climate is perhaps the greatest challenge to forest managers world-wide. Since most of the world's forests are found in areas where temperature, light or nutrients limit tree growth and productivity, recent global warming, changes in atmospheric composition (i.e. increased concentrations of nitrogen compounds and CO_2 from massive societal emissions) and local increases in sunlight and precipitation have benefited the growth of many forests in recent decades, when and where water has not been limiting (Boisvenue and Running 2006). Although in some instances climate change may have been beneficial for forests, the growing consensus is that climate change is ultimately a great threat to forest health.

At present, there are more options for detecting climate related phenomena which may be the pivotal causes for forest dieback and disease outbreaks than active

A. Riebau (✉)
Retired from USDA Forest Service Research and Development, Nine Points South Technical PTY LTD, Clarkson, WA, Australia
e-mail: ariebau@ninepointsouth.com.au

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_57,

adaptation strategies. For example, the US Forest Service's aerial surveys of the southwestern United States pinyon/juniper woodlands in 2002 and 2003 revealed significant tree die-off covering more than 4,600 square miles ($12,000\,km^2$). The effect was so dramatic that it could be detected by satellite. The region's 60,000 square miles (about $155,000\,km^2$) of pinyon/juniper woodlands browned starting in 2002 (Jensen 2006).

A previous multi-year drought in the 1950s resulted in less tree mortality. To understand how the two droughts episodes differed, University of Arizona researchers compared the four driest consecutive years of the earlier drought, 1953–1956, with those of the recent drought, 2000–2003, and found the more recent drought "by every measure. . .hotter." The high heat combined with the extreme dryness put the trees under so much water stress that the trees could not make enough pine sap to defend themselves against the insects (Jensen 2006).

In the example above, the forest managers as of yet have not developed comprehensive means to adapt this large area of forest to climate change but are working towards this goal of adaptive management (BLM 2000). Adaptive management for forest ecosystem threats may help make forests and forestry practices more able to cope with disturbances (Tompkins and Adger 2004), but they must take climate change and human influenced climate variability into account or money and time may be wasted on ineffectual treatments.

Adaptive strategies for forestry must also include an analysis of climate informed forest fire potentials. In general, fire danger has been reduced and intense fires avoided using prescribed burning. In theory and practice, prescribed fires allow forest understorey fuels to be burnt at lower intensities and thus under less dangerous fire conditions (Long 2002).

As an adaptive strategy this looks to be very easy to apply. In practice it is not. The huge areas that need prescribed fire treatments are daunting (e.g. Siberia, Canada), in some areas the risk to homes is almost un-manageable (e.g. California, Europe) (FAO 2002; State of California 2001). As fire seasons lengthen (Wotton and Flannigan 1993; Wotton et al. 2003), almost universally world-wide, personnel and equipment that might be used to conduct prescribed fires are engaged fighting wildfires during the short window of opportunity for prescribed burns (NIFC 1995). By providing seasonal predictions of fire weather potentials and fuels conditions, fire and forest managers can better schedule and apply prescribed fire. They can also better predict where and when arson or natural ignition fires are likely to propagate (Li 2009).

An adaptive strategy that could be employed for megafires, a category of forest fires that are too large and intense to fight, would be to use climate and fire weather predictions to estimate how far fires will travel (Bartlett et al. 2009). This would improve evacuation of people. Finally, air quality impacts from smoke can be lessened through the use of models to predict the likely transport and concentrations of smoke before they reach un-prepared publics (Riebau and Fox 2001), thus allowing prescribed fire to be better utilised in adaptive strategies.

References

Allen CD (2009) Climate-induced forest dieback: an escalating global phenomenon? Adapting to climate change. Unasylva 60:43–49

Bartlett T, Leonard M, Morgan G (2009) The *mega-fire* phenomenon: some Australian perspectives. Institute of Foresters in Australia (IFA). Bushfires & forest management resource site. IFA, Yarralumla, 11pp. http://www.forestry.org.au/news/articlefiles/1186-Megafire-final%20Draft.pdf

Bernier P, Schoene D (2009) Adapting forests and their management to climate change: an overview. Unasylva 60:5–11

BLM (2000) Assessment and research needs for development of a Piñon-Juniper management strategy on the Colorado Plateau. Bureau of Land Management (BLM), United States Department of the Interior, Colorado Plateau Science Committee. http://www.mpcer.nau.edu/pjwin/blm_strategy.html

Boisvenue C, Running SW (2006) Impacts of climate change on natural forest productivity – evidence since the middle of the 20th century. Glob Change Biol 12:862–882

FAO (2002) Guidelines on fire management in temperate and boreal forests. Forest protection working papers – FPF/1, Forest resources development service, Forest Resources Division, Rome. http://www.fao.org/docrep/009/ag041e/AG041E00.HTM

Jensen MN (2006) Underlying cause of massive Pinyon Pine die-off revealed. *Alumnus*-Summer 2006/Global Warming. A special report: UA scientists' current investigations and findings. The University of Arizona. http://www.uagrad.org/Alumnus/gw/pine.html

Li R(T) (2009) Evaluation of the wildfire ignition risk by the aid of fuzzy logic. University of Georgia, Athens, USA, 30pp. http://www.ucgis.org/summer2007/studentpapers/project_UCGIS_update3_li_rongxia.pdf

Long AJ (2002) Benefits of prescribed burning. FOR 70, School of Forest Resources and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu/pdffiles/FR/FR06100.pdf

NIFC (1995) Federal Wildland Fire Management. Policy and Program Review. USA Department of the Interior, USA Department of Agriculture, Washington, 45pp. http://www.nifc.gov/fire_policy/mission/1995_fed_wildland_fire_policy_program_report.pdf

Riebau AR, Fox D (2001) The new smoke management. Intern J Wildl Fire 10:415–427

State of California (2001) California fire plan. Overview. California State Board of Forestry and Fire Protection and California Department of Forestry and Fire Protection. Sacramento. http://cdfdata.fire.ca.gov/fire_er/fpp_planning_cafireplan

Tompkins EL, Adger WN (2004) Does adaptive management of natural resources enhance resilience to climate change? Ecol Soc 9:10. http://www.ecologyandsociety.org/vol9/iss2/art10

Wotton BM, Flannigan MD (1993) Length of the fire season in a changing climate. For Chron 69:187–192

Wotton BM, Martell DM, Logan KA (2003) Climate change and people-caused forest fire occurrence in Ontario. Clim Change 60:275–295

III.4.3 Coping with Extreme Meteorological Events

III.4.3.(A) Problems and Solutions in Coping with Extreme Meteorological Events in Forestry, and Challenges Remaining for the Use of Science to Contribute to Problem Analyses and Designing Valuable Solutions in the Context of Forest (Agro) Meteorology

Kees Stigter

Science has contributed at least a definition of forest and forest lands based on tree formation structure as well as of trees outside forests (Box III.4.15). Giving developments in tree use and agroforestry as well as in agriculture taking place in forests, science may want to revise such definitions from time to time.

Box III.4.15

The FAO definition of forest or forest lands is based on tree formation structure, i.e., percentage of crown cover, and height of tree species, plus the area covered. Other woodlands include shrub cover and forest fallow. Shrubs are "woody perennial plants, generally of more than 0.5 m and less than 5 m in height on maturity and without a definite crown. The height limits for trees and shrubs should be interpreted with flexibility, particularly the minimum tree and maximum shrub height, which may vary between 5 and 7 m approximately". This definition thus embraces all low-growing woody formations. Bellefontaine et al. (2002), after giving the definitions above, indicated "trees outside forests" to be trees and shrubs on land not defined as forest and other wooded land.

This may include agricultural land, including meadows and pasture, built-on land (including settlements and infrastructure), and barren land

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_58,

(including sand dunes and rocky outcroppings). It includes agroforestry systems, orchards, small clumps of trees, such as in permanent meadows and pastures, trees growing on farms and in urban and peri-urban zones, in lines along rivers, canals and roads, and in gardens, parks and towns They defined that this may also include trees on land that fulfils the requirements of forest and other wooded land except that: (i) the area is less than 0.5 ha; (ii) the trees are able to reach a height of at least 5 m at maturity in situ but where the stocking level is below 5%; (iii) trees not able to reach a height of 5 m at maturity in situ where the stocking level is below 10%; (iv) trees in shelterbelts and riparian buffers of less than 20 m width and 0.5 ha area.

The most important extreme meteorological events related to forestry, and to agriculture taking place in forest areas (Michon 2005), may be wildfires and bushfires, strong wind systems, long term droughts and floods as well as, to a lesser extent, long heat and cold waves, the latter including frost, snow and icing. Of these, fires are more damaging to forests than to any other natural or production system. The only atmospheric phenomenon involved in (a minority of) their causes is dry lightning (e.g. Rorig 2003). Agriculture can be used to reduce farm forestry risks (Stewart 2005; Sebastian 2006; Saroso 2007). Forests are generally protective for forest agriculture.

Physically, fire is not an element, it is a phenomenon, a reaction, a process (Pyne 2006).Today some places suffer from too much fire, some from too little or the wrong kind, but everywhere fire disasters appear to be increasing in both severity and damages, with serious threats to public health, economic wellbeing and ecological values (Pyne 2001, cited in Goldammer 2003). Wildfires during drought years continue to cause serious impacts to natural resources etc. over large areas (Goldammer 2003, 2006). Basic review literature is given in De Melo-Abreu et al. (2010).

We typically have an interaction between fires, also that majority not caused by atmospheric events (e.g. Pyne 2006), with high(er) temperatures, (increasing and more severe) droughts and strong winds (De Melo-Abreu et al. 2010). Boreal forests are for example estimated to contain close to 40% of the world's terrestrial carbon and climate change appears this way to get a huge impact on the global carbon cycle through increased fires, including those of peatlands (Goldammer 2003, 2006). An increase in the frequency of extreme droughts has also contributed to a worsening, largely manmade (often agriculture related) fire situation in the Mediterranean, the Balkan, Mongolia, Australia and Africa and even in the tropical rainforests worldwide (Goldammer 2003, 2006).

What makes it worse are the positive atmospheric feedback effects on local scales, fires causing soil degradation leading to more floods and droughts, and on global scales, reducing precipitation and increasing lightning while causing a net loss of carbon to the atmosphere amidst releasing large amounts of greenhouse gasses (Goldammer 2003, 2006). If any new outlook would help, it would be "fire-as-biology" in which fire control is a variety of biological control, much like integrated pest management; it is a relationship outside which it is only a (more and more serious) problem (Pyne 2006).

Forests slow water movement and thus precipitate sediments, capture nutrients, and build the soil. The presence or absence of forest cover may decide the ultimate fate of human society (Wadsworth 1998–2004). Tropical forests provide soil protection, a high soil infiltration rate, and, where soil is deep, substantial storage. The draft on soil water is greatest under forests with their deep-rooted trees and high rates of transpiration. Between storms porous soils again become highly receptive to new water. Measurements over time suggest that, under closed forests, about 15–20% of the rainwater is held in the canopy. The forest floor minimizes landslides by absorbing the shock of intense rainfall as do the dense and deep tree-root systems. Studies show the superiority of forest over other types of vegetation cover in this function (Wadsworth 1998–2004).

Flood events, depending upon the magnitude, can produce destructive effects on tree stands, as flood currents may be sufficient to topple trees (De Melo-Abreu et al. 2010). However, forests are normally related to floods otherwise. The effectiveness of forests in controlling erosion varies with the climate, slope, soil condition, and the character of the forest. The densest forests, which permit few living plants in the ground layer, may be less protective than more open forests with herbs, grasses, or young trees which hold the litter in place, particularly on slopes. Improved (tree) fallow has also such properties (Wilkinson and Elevitch 1998–2004).

Many trees, and palms in particular, tend to concentrate rainfall towards their main stem. This stemflow concentrates flow down slope that can, in extreme cases, cause severe erosion. Where these problems become serious, they can be lessened by silvicultural practices (Wadsworth 1998–2004; Young 1998–2004). It was argued by Chambers (1990) that looking at microenvironments the ways farmers do would be beneficial for understanding such practices. Kinama et al. (2007) showed the usefulness of microenvironment descriptions for understanding run off decrease and erosion reduction on sloping land with such practices.

Forest degradation can result in increased runoff and thus increased flooding potential within local watersheds (Chomitz and Kumari 1998). However, the relationship between deforestation and (large scale) flooding is not straightforward and many other causes may be involved and be more important, but increased run-off can wash away fields or cover them with debris (e.g. Winkler 1999; ETFRN 2005/2006). Good standing riparian zone vegetation, especially trees, can protect farms and farm animals from wind, rain, frost and floods. It prevents the erosive action of floods if there is a tendency of flooding (Sebastian 2006) and thus protects the crops from floodwater velocity and erosive power (Stigter et al. 2003).

The reality is that direct links between deforestation and floods are far from certain. Although the media attribute virtually every flood-related tragedy to human activities – particularly to agricultural expansion and timber harvesting – hydrological systems are so complex that it is extremely difficult to disentangle the impacts of land use from those of natural processes and phenomena (FAO/CIFOR 2005).

Although a great deal is known about hydrological processes and the relationship between forests and floods, this knowledge is often used to make generalisations that are frequently inappropriate or misleading. It is commonly believed that forests are necessary to regulate stream flow and reduce runoff, and to some extent this is true.

But, in reality, forests tend to be rather extravagant users of water, which is contradictory to earlier thinking (FAO/CIFOR 2005). Moreover, all floods cannot and should not be completely prevented. In many floodplains, certain crops even depend on seasonal flooding, but steps can be taken to limit the adverse impacts of floods and to ensure effective responses to flooding events (Stigter et al. 2003; FAO/CIFOR 2005). The Forestry Research Programme of DFID designed a cluster of related projects to make use of improved instrumentation, better mathematical modeling and powerful geographic information systems to produce more reliable prediction of the association between vegetation (including forests) and dry season stream flows. DFID (2005) summarizes the findings from the individual projects in this cluster and derives policy lessons.

In Ruck et al. (2003) there are detailed reviews on wind effects on trees in forestry structures under storm conditions while Wisse and Stigter (2007) deal with fire propagation by wind for African conditions. Scientifically still much remains to be done, while understanding should be better used for protection (De Melo-Abreu et al. 2010). Snow, ice and frost as well as extreme temperatures are relatively minor disturbances in forestry with some local exceptions and secondary effects (De Melo-Abreu et al. 2010).

In some temperate forests, rapid climate change and accompanying extreme events, such as droughts, floods, and wind storms, could lead to increases in diseases, insects, landslides and wildfires, that could worsen tree mortality and, in some cases, replace forests by grasslands. Some of the models used in the USA National Assessment indicate that forest productivity overall is likely to increase, leading to increased supply of certain types of timber, though possible interactions with extreme events and other disturbances could reduce these gains (Bloomfield 2000).

References

Bellefontaine R, Petit S, Pain-Orcet M, Deleporte P, Bertault J-C (2002) Trees outside forests. Towards better awareness. FAO Conservation Guides 35, Rome, 216pp

Bloomfield J (2000) The potential impacts of global warming on America's forests. GLOBAL WARMING: Early Warning Signs. http://www.climatehotmap.org/impacts/forests.html

Chambers R (1990) Microenvironments unobserved. Gatekeeper Series 22, IIED, London, 15pp

Chomitz MK, Kumari K (1998) The domestic benefits of tropical forest preservation: a critical review emphasizing hydrological functions. World Bank Research Observer 13(1):13–35

De Melo-Abreu JP, Daldoum MA, Andrews PL, Bastos TX, De Groot WJ, Fleming R, Fleming R, Fujioka F, Goldammer JG, Govind A, Harrison J, Keenan T, Price D, Statheropoulos M, Stigter K, Wain A (2010) Applications of meteorology to forestry and non-forest trees. Chapter 11 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

DFID (2005) From the mountain to the tap: how land use and water management can work for the rural poor. http://www.frp.uk.com/assets/Water_book.pdf

ETFRN (2005/2006) Forests, water and livelihoods. ETFRN Newsletter 45–46. http://www.etfrn.org/etfrn/newsletter/pdf/etfrnnews4546.pdf

FAO/CIFOR (2005) Forests and floods. Drowning in fiction or thriving on facts? RAP Publication 2005/03, Forest Perspectives 2, FAO, Rome. http://www.fao.org/docrep/008/ae929e/ae929e00.htm

Goldammer JG (2003) Fire ecology of the recent anthropocene. Proceedings of the 5th Symposium on Fire and Forest Meteorology, Orlando. http://ams.confex.com/ams/FIRE2003/techprogram/program_160.htm

Goldammer JG (2006) Fire ecology of the recent anthropocene. In Ehlers E, Kraft T (eds) Earth system science in the Anthropocene. Springer, Berlin/Heidelberg/New York pp 63–85

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2007) Contour hedgerows and grass strips for erosion and runoff control in semi-arid Kenya. Arid Land Res Manag 21:1–19

Michon G (2005) Forest culture. The Overstory, Paper 158. PAR, Holualoa, USA. http://www.mail-archive.com/sustainablelorgbiofuel@sustainablelists.org/msg52658.html

Pyne SJ (2006) The element that isn't. In: Fire ecology: issues, management, policy and opinions. Fire Ecol 2:1–6. http://www.fireecology.net/pdfs/vol2/pyne.pdf

Rorig M (2003) Forecasting dry lightning in the western United States. Proceedings of the 5th Symposium on Fire and Forest Meteorology, Orlando. http://ams.confex.com/ams/FIRE2003/techprogram/paper_65549.htm

Ruck B, Kottmeier C, Mattheck C, Quine C, Wilhelm G (eds) (2003) Wind effects on trees. University of Karlsruhe, Germany, 375pp

Saroso O (2007) West Lampung livelihoods benefit from agroforestry. The Jakarta Post, 10 September, p 19

Sebastian M (2006) Riparian buffer zone restoration for food security. The Overstory, Paper 167. PAR, Holualoa, USA, 10pp. May be read at http://www.ileia.org/index.php#m_issues (search: overstory)

Stewart A (2005) Risk management for farm forestry: tips for farmers. The Overstory, Paper 151. PAR, Holualoa, USA, 10pp

Stigter CJ, Das HP, Murthy VRK (2003) Beyond climate forecasting of flood disasters. Invited lecture on the opening day of the fifth regional training course on Flood Risk Management (FRM-5) of the Asian Disaster Preparedness Center (Bangkok) and the China Research Center on Flood and Drought Disaster Reduction (Beijing), Beijing, September. Available from ADPC (Bangkok) on CD-ROM. Also available at http://www.agrometeorology.org/fileadmin/insam/repository/ADPC2mp.pdf

Wadsworth FH (1998–2004) Forests and water. Paper 80 In: Elevitch CR (ed) The overstory book. cultivating connections with trees, 2nd edn. PAR, Holualoa. http://agroforestry.net/overstory/overstory80.html

Wilkinson K, Elevitch C (1998–2004) Improved fallow. Paper 42 In: Elevitch CR (ed) The overstory book. cultivating connections with trees, 2nd edn. PAR, Holualoa. http://agroforestry.net/overstory/overstory42.html

Winkler D (1999) Forestry, floods, and hydroelectricity: China's natural forest protection project and its impact on Tibetan areas. Sinosphere Vol. 3.2 at www.chinaenvironment.net/sino/sino5; http://www.danielwinkler.com/forestry__floods_and_hydroelectricity_1999.htm

Wisse JA, Stigter K (2007) Wind engineering in Africa. J Wind Eng Ind Aerodyn 95:908–927

Young A (1998–2004) Effects of trees on soils. Paper 61 In: Elevitch CR (ed) The overstory book. Cultivating connections with trees, 2nd edn. PAR, Holualoa. http://agroforestry.net/overstory/overstory61.html

III.4.3.(B) Designing and Selecting Efficient Early Warning Strategies and Increasing Their Efficiencies in Forestry

Al Riebau

Forests are often at the heart of a national economic and social welfare (Diamond 2005). They are resilient yet they are subject to damage from extreme disturbance events. Such events can be categorized in many different ways, but they can often have a root cause linked to weather. The high potential for adverse climate change, with increased potential for extreme weather that can cause forest damage (FAO 2008), will likely increase the need for improved warning strategies. Early warning systems are categorized in Box III.4.16. The need will increase for several reasons.

Box III.4.16

For the purpose of discussion, we define four categories of early warning system with regard to the severity of extreme disturbances, presented in their assumed order of importance. The first category is "significant and immanent harm to people and structures within forest boundaries". Examples of early warnings in this category are warnings of floods, landslides, storms, and fires that endanger dwellings. The second category is "significant and immediate harm to forest resources". Examples of early warnings in this category are forest fire warnings and insect pest outbreaks. The third category is "significant and immediate harm to forest ecosystem functions and sustainability". Examples of this category are drought warnings and warnings of long-term climate shift. The fourth category is warnings of chronic threats to forest existence. Examples of this severity category of threat are early warnings of invasive species occurrence and warnings of exceedence of critical loads from atmospheric deposition (Daterman et al. 2004).

There is also an issue of synergism in multiple early warning systems, because two or more early warning systems, whose output is combined, potentially

A. Riebau (✉)
Retired from USDA Forest Service Research and Development, Nine Points South Technical PTY LTD, Clarkson, WA, Australia
e-mail: ariebau@ninepointsouth.com.au

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_59,

provide an increase in information and efficiency that might not be obtained by either system alone. A natural example to discuss is fire danger and extreme fire weather warnings. Often, such early warning systems can be linked, but they may also be implemented as separate systems. When they become seamlessly linked, a synergism occurs between data sources, information transmission, and operational use. For example, areas of extreme fire danger and areas of potential extreme fire behaviour can be matched. When developing new early warning systems or improving existing ones for a particular purpose, designers should fully investigate what other systems, even systems which are far from the topic of interest, cover some or all of the geographic area of interest. Some examples of such cases which might offer synergisms to forestry early warning systems are agricultural management, water management, air quality, maritime safety, aeronautical safety, road traffic safety, military safety, hunter safety and recreation. Such ideas may be explicitly implemented in multi-hazard systems (WMO 2007).

First, the spatial extent of extreme weather events may increase to the scale of continents as climate-driven phenomena become continental rather than regional (Moritz et al. 2002). Secondly, the frequency of occurrence of such events is also likely to increase (IPCC 2001). Thirdly, also the amplitude of such events may increase as the atmospheric system becomes more energetic due to higher planetary atmospheric trapping of heat (Veiga et al. 2009). Finally, the temporal duration of extreme events may increase. Simply put, extreme events potentially may increase in the number of times they happen, how great an area is impacted, how severe they are, and how long they last. The costs of such events will naturally increase as well, making avoidance and mitigation of such losses of greater international significance (Allen 2009).

A primary avoidance and mitigation strategy is through effective and timely early warnings. Early warnings can, naturally, help to avoid disasters. It is common practice in most developed and many developing countries to provide early warning of extreme forest fire danger conditions. Although such warnings are common place, they differ in how they are developed (what data are used and how indices are calculated), but generally they have proved useful to foresters (Nesterov 1949; Keetch and Byram 1968; Global Fire Monitoring Centre 2008). During high fire danger warnings, forest fires are avoided by restrictions on forest use and forest access.

The concept of early warnings as a mitigation strategy may sound foreign. However, if separate disturbance events follow each other closely, understanding of their linkages can be a great advantage to mitigation. For example, a catastrophic forest fire can so destabilize the landscape that mudslides can follow after heavy rainfall. Thus early warning of future heavy rainfall can help to mitigate landslides and loss of structures. Recently, this linkage and need for using early warnings to develop mitigation measures from forest fire destabilized landscapes have been demonstrated for the United States in southwestern California (Bustillo 2003; US Geological Survey 2004).

The United Nations has recommended that in order to be effective, early warning systems have to integrate four elements: (i) a knowledge of the risks faced; (ii) a technical monitoring and warning service; (iii) the dissemination of meaningful warnings to those at risk; and (iv) public awareness and public preparedness to act. Failure in any one of these elements can mean failure of the whole early warning system (ISDR 2006a).

Early warning system descriptive measures of excellence are accuracy of prediction, repeatability, forecast duration, spatial resolution, affordability, and scientific resonance or credibility (Riebau and Fox 2005; Riebau 2009). Accuracy of prediction is the ability to depict what actually will happen and is perhaps the first measure of excellence that comes to mind. However, if a prediction is inaccurate, it often best overpredicts severity or be conservative. As a rule-of-thumb, complete accuracy sounds better than it may actually be, as it often is best to overpredict severity of impact for environmental issues; this is to be preferred over complete fidelity to predicted reality because a margin of safety is ensured (Blodget et al. 1998). Such a margin of safety can be, and most often should be, designed into an early warning system.

Early warnings must also be repeatable; that is they must be able to repeat the same result from the same input information and be systematic. Systematic errors can among others occur from human errors in interpretations, miscoding of computer programs, errors in information transmission and database errors. Forecast duration must also be appropriate to the forecast involved. In agricultural meteorology the reach of future predictions is increasing as computer capacity and remote sensing data have allowed meteorology to be modeled farther into the future with increasing skill. For extreme fire weather, warning predictions of up to three months into the future would be desirable. Although they are presently not scientifically supportable, they are being attempted in the United States.

Spatial resolution is also an issue that must be considered. For forestry, high granularity of spatial resolution is perhaps not as important as for field crops. Naturally, many useful early warning systems, such as fire danger or frost warnings, are often not presented as gridded (i.e. spatially resolved) information, but GIS generated maps are increasingly being used in warnings. That said, depending on the early warning being given, a grid may have a resolution of 100 km while for others a resolution of 10 km or less may be appropriate (Dokas 2008). One critical point to consider in designing early warning systems is that granularity of scale for gridded data must be decided and fixed at the beginning of the system design, as adding higher spatial resolution afterwards is commonly more expensive or not possible.

Affordability of early warning systems pivots on the spatial resolution, forecast duration, repeatability, and accuracy of the system. Generally, as these four factors increase, the cost of early warning systems will increase in correspondence with input data amounts, types, and quality, computer time, display needs, educational needs, and public communication needs.

Fig. III. 4.2 Four elements of people-centred early warning systems (ISDR 2006b)

Finally, the issue of scientific resonance or excellence must be considered. An early warning system that is not grounded in solid research (e.g. in the algorithms it employs, in the information sources it uses, in the concepts it employs) and is not supported in peer-reviewed scientific literature, is of course always open to criticism and may well be inefficient in its application. The system and its implementers will also perhaps open themselves to liability should warnings fail or cause unwarranted expense. Generally, for advanced and complicated services, scientific excellence will cost the least of any other measures but may be perhaps the easiest to overlook. The United Nations has also outlined four elements of people-centred early warning systems which the reader should also consider (Fig. III.4.2; WMO 2007).

In conclusion, the following suggestions are made specifically for forestry early warning systems as ideas to consider

- Improved and more efficient and effective fire danger warning systems will need to be implemented world-wide. Although systems in North America, Australia, and Europe may be expected to get improved from within, the rest of the world needs help in improving their systems. Much can be achieved to further this goal by developing fire meteorology observation infrastructure in countries and supplementing the observations with mesoscale meteorological models (Riebau and Qu 2005).
- Improved fire behavior modeling will allow forestry organizations to give better warnings to the public and fire fighters. This cannot be achieved unless there are accurate maps of forest fire fuels and an actively updated database of current fuel conditions, including fuel moisture. This work can be furthered by remote sens-

ing, with programs like Global Observation of Forest Cover and Global Observation of Land Dynamics (GOFC/GOLD) being useful to the effort (Riebau and Qu 2005).

- Mesoscale meteorological models could be used to provide early warning information on likely areas of forest pests. It would for example be possible to use the models, supplemented and adjusted with available ground based observations, to provide maps of regional areas where winter temperatures were too high to lower bark beetle infestations. Such areas could then become high priority areas for ground surveys and subsequently for treatments if the pest infestations were found (Daterman et al. 2004).
- The use of smoke dispersion modeling, for providing early warning for public smoke exposures, has been demonstrated in the USA and a few other countries. The techniques for such modeling are well known and readily available. Although there are inaccuracies in the models used to date, simulations have proven useful and prudent, especially when a long lead time for smoke warnings can save morbidity/mortality in sensitive populations. Forest fire smoke dispersion modeling, whether using simple or complex approaches, should be considered in fire prone areas world-wide (Riebau and Qu 2005).
- As climate changes, air pollution stressor impacts to forests may increase. Air pollution models, especially models for ozone exposure, could be utilised to allow for early warnings for forest health stressors. In both the United States and the European Union, air quality forecasting systems are being implemented that provide daily ozone forecasts. A product could be added to provide a seasonal summation of ozone exposures for forest health in these countries. When air quality forecasting techniques become more widespread, such summations may be possible in many other locations in the world (Bytnerowicz et al. 2008; Grulke et al. 2008).

References

Allen CD (2009) Climate-induced forest dieback: an escalating global phenomenon? Unasylva 231/232, 60(1–2):43–49

Blodgett JE, Parker LB, McCarthy JE (1998) Air quality standards: the decisionmaking process. National Council for Science and the Environment, Environment and Natural Resources Policy Division. CRS Report 97-722 ENR. http://cnie.org/NLE/CRSreports/air/air-21.cfm#Summary

Bustillo M (2003) Fires bring hazards of landslides. Los Angeles Times, Tuesday, November 4, in print edition A-1. http://articles.latimes.com/2003/nov/04/local/me-slides4

Bytnerowicz A, Arbaugh MJ, Anderson C, Riebau AR (2008) Integrating research on wildland fires and air quality: needs and recommendations. In: Bytnerowicz A, Arbaugh MJ, Riebau AR, Anderson C (eds) Wildland fire and air pollution. Elsevier, Amsterdam, pp 591–608

Daterman GE, Wenz JM, Sheehan KA (2004) Early warning system for douglas-fir tussock moth outbreaks in the western United States. West J Appl For 19:232–241

Diamond J (2005) Collapse: how societies choose to fail or succeed. Viking/Penguin, New York, 592pp

Dokas IM (2008) Early warning systems: views and application domains. A report submitted to the Irish Environmental Protection Agency. Technical Report SCEWA, Cork, Ireland, no pages given

FAO (2008) Strategic framework for forests and climate change, a CPF proposal. FAO, Rome, xiii + 44pp. http://www.fao.org/forestry/media/16639/1/0/
Global Fire Monitoring Centre (2008) Towards the development of a global early warning system for wildland fire. Freiburg University/United Nations University. http://www.fire.uni-freiburg.de/fwf/EWS.htm
Grulke NE, Minnich RA, Paine TD, Seybold SJ, Chavez DJ, Fenn ME, Riggan PJ, Dunn A (2008) Air pollution increases forest susceptibility to wildfires: a case study in the San Bernardino mountains in Southern California. In: Bytnerowicz A, Arbaugh MJ, Riebau AR, Anderson C (eds) Wildland fire and air pollution. Elsevier, Amsterdam, pp 365–403
IPCC (2001) Climate Change 2001: the scientific basis. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change. 83pp. http://chaser.env.nagoya-u.ac.jp/~kengo/lec/IPCC_TAR-FRONT.pdf
ISDR (2006a) Global survey of early warning systems. UN International Strategy for Disaster Reduction Committee Report A/C.2/61/CRP.1, Geneva, 13pp. http://www.un.org/ga/61/second/ac261crp1.pdf
ISDR (2006b) Developing early warning systems: a checklist. Proceedings of the 3rd International Conference on Early Warning, Bonn, 27–29 March. UN International Strategy for Disaster Reduction, Geneva, 10pp. http://www.unisdr.org/ppew/info-resources/ewc3/checklist/English.pdf
Keetch JJ, Byram GA (1968) A drought index for forest fire control. USDA Research Paper SE-38. Southeastern Forest Experiment Station, Asheville, number of pages not available
Moritz RE, Bitz CM, Eric J, Steig EJ (2002) Dynamics of recent climate change in the arctic. Science 297:1497
Nesterov VG (1949) Combustibility of the forest and methods for its determination. In Russian. USSR State Industry Press, Moscow. Number of pages not available.
Riebau AR (2009) Port Hedland air quality management policy framework. State of Western Australia. Western Australia Department of Environment and Conservation, Perth, internal draft document, November, 106pp.
Riebau AR, Fox DG (2005) Damage assessment of agrometeorological relevance from natural disasters: economic and social consequences. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin, etc, pp 119–135
Riebau AR, Qu JJ (2005) Application of remote sensing and GIS for analysis of forest fire and risk assessment of forest degradation. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin, etc, pp 335–355
US Geological Survey (2004) New mudslides expected with heavy storms in southern California. Science Daily of 24 February. http://www.sciencedaily.com/releases/2004/02/040224105346.htm
Veiga JAP, Pezza AB, Simmonds I, Leite da Silva DP (2009) A new interpretation for hurricane transition based on environmental energetics. Proceedings of the 9th International Conference on Southern Hemisphere Meteorology and Oceanography, Melbourne, 9–13 February. http://www.bom.gov.au/events/9icshmo/manuscripts/T1200_Veiga.pdf
WMO (2007) WMO multi-hazard early warning demonstration projects. Outline for documentation of good practices in early warning systems. Expert meeting on national meteorological and hydrological services' participation in disaster risk reduction coordination mechanisms and early warning systems, 26–28 November, Geneva. http://www.wmo.ch/pages/prog/drr/events/coordination-mechanisms-2007/documents/2007.11.28-Outlines DocumentationEWS.doc

III.4.4 Tactical Decision Making Based on Weather Information

III.4.4.(I) Problems and Solutions in Using of and Coping with Weather Phenomena in Need of Tactical Decision Making and Challenges Remaining for the Use of Science to Contribute to Problem Analyses and Designing Viable Solutions in This Context: Forest (Agro)Meteorology

Dick Felch and Kees Stigter

Forest management involves a variety of objectives, including the output of forest products, the provision of recreation opportunities, the protection of the biological elements (such as endangered species), the maintenance of watershed values, the conservation of soil, the control of pests and diseases and the reduction of losses due to wildfire (Church 2007).

As discussed in Sect. III.4.2.(i), tactical decision making in forestry often represents seasonal type decision making. Because of the complexity and vastness of many forested areas, effective decision making at this level is critical to preparing for the shorter term operational decisions that will be required later in season. In many cases, the opportunities for risk avoidance are limited; the majority of the tactical decisions involve coping with risk to minimize damage by effectively using resources (Church 2007).

This section focuses on three areas where short term and medium- to long-range weather and climate forecasts could be used to support tactical planning decisions as they effect day-to-day forest management operations: fire weather management; insect and disease management; and seasonal operations such as seedling establishment or harvest operations. The last two are here only shortly discussed in Box III.4.17. Most of the programs designed to assist in these areas are referred to as "early warning systems". Section III.4.3.(B) discusses in more detail what is needed for an effective early warning program. In this section, several specific programs will be described and how the information is disseminated to the user community.

D. Felch (✉)
National Weather Service, NOAA (retired), Chanhassen, MN, USA
e-mail: dickfmn@gmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_60,

Box III.4.17

Insect management and disease management are important parts of forest management. There are two aspects: forecasting the development of an insect infestation or disease infestation, and forecasting the movement of existing infestations. The quantification of disease is an important concern and necessary for justifying disease control measures. The losses from diseases and insects are significant but very difficult to quantify, because there is not enough of an understanding of how much growth loss, mortality and cull are attributable to the disease (Worrall 2007).

An important component of understanding how and when and where an infestation may occur is to examine the components of seasonal life cycles and which part of the life cycle is particularly responsive to the influence of weather and climate. For example, Logan and Powell (2001) have developed an empirical model of the mountain pine beetle thermal ecology, utilizing detailed temperature observations. Because of temperature changes with elevation, elevation can in fact be a limiting factor. It follows that insects like the mountain pine beetle with direct temperature control of seasonality are pre-adapted to take advantage of a warming climate.

From the selection of sites for afforestation to the planning of the forest products, weather forecasts play a significant role for the foresters in their seasonal operations (Das et al. 2010). Prescribed burning is an important element in controlling the threat of fire by eliminating ground fuels. Prescribed burning in turn creates the need for weather and climate forecasts for smoke management (Pacific Northwest Research Station 2006).

Seedling establishment may be done by natural reseeding, seeding from aircraft or the planting of saplings. Temperature and particularly precipitation patterns play a significant role in the germination and growth of plant stands (Das et al. 2010). The timing of planned plantings can be adjusted on the seasonal outlooks of temperature and precipitation.

Harvest operations may be adjusted based on fire danger forecasts if fire danger remains high, determining whether logging operations should be initiated or allowed to continue. Similarly, fire danger forecasts can also be used to determine whether or not parks or forests should remain open for recreational purposes (Das et al. 2010).

From a tactical perspective, fire weather planning and management is one of the greatest problems facing forest managers (Das et al. 2010). The majority of forest fires are the direct result of human activities, either accidently through carelessness, or unfortunately, through deliberate arson. For tactical decision making current forest conditions information and future weather forecasts can be utilized in early warning systems to anticipate the risk of fire occurring at any given time.

Such decisions can then be made to (a) control the levels of activity in forest systems and (b) prepare in advance for the allocation of resources where fires are most likely to occur. Many countries around the world have some type of early warning system. There are also efforts to develop a global early warning system (GFMC 2009). See also Sect. III.4.3.(B) for strategical issues.

Early warning of wildland fire and related hazards includes a variety of meteorological approaches and systems to identify precursor developments and assess/predict the escalation of wildland fire events (EWC II 2003). The Global Fire Monitoring Center Early Warning System (EWS) and its various programs can be viewed on their website (GFMC 2009). A complete inventory of systems available worldwide can be found under "Global, Regional and National Fire Weather and Climate Forecasts" of the GFMC Wildland Fire Early Warning Portal (http://www.fire.uni-freiburg.de/fwf/fwf.htm). Several of these programs are described in detail in proceedings of the Second International Conference on Early Warning (EWC II 2003). There are several common elements to most of these systems, where science has to play a more important role:

- Assessment of fuel loads. Ground measurements and to a certain extent also satellite generated information allow to determine the amount of fuels (= combustible materials) available for wildland fire. This is important because dryness and fire risk alone do not determine the extent and severity (of impact) of fire.
- Prediction of fuel moisture content. This term is closely related to the readiness and ease of vegetation to burn. EWSs include meteorological danger indices and space borne information on vegetation dryness (intensity and duration of vegetation stress) and soil dryness. Prediction of inter-annual climate variability (as to drought) particularly related to ENSO is important for preparedness planning in many countries.
- An assessment of the impact of future weather on these conditions (EWC II 2003).

In the US, predicting the influence of weather on fire ignition and fire spread is an operational requirement for national and global fire planning by the US National Interagency Fire Center (NIFC), a multi-agency effort which includes several regional centers which service various parts of the country. NIFC's Predictive Services produce national wildland fire outlooks and fire assessment products at weekly to seasonal time series (EWC II 2003). Detailed descriptions and examples of these products are available (NIFC 2009).

As earlier indicated, seasonal outlooks are very important. Forecasts and assessments range from bi-annual workshops in different parts of the country to seasonal, monthly, biweekly, weekly and daily products. From a tactical perspective, these products provide various agencies a time window to prepare for a potential fire outbreak. This includes having the fire fighting equipment available and ready. This could include both ground equipment and aircraft, sufficient manpower to deal with a fire if it does break out, and alerting other governmental authorities. An example of a seasonal outlook is shown in the graphic (Fig. III.4.3) of Box III.4.18 (NIFC 2009).

Box III.4.18

The map below shows the Significant Fire Potential Forecast (wildland) for May through August 2009 across the western half of the US and Alaska. Significant fire potential is defined as the likelihood that a wildland fire event will require mobilization of additional resources from outside the area in which the fire situation originates. Areas highlighted as "Above Normal" are likely to require additional external resource mobilization. The results indicate that there will be above normal significant fire potential across portions of California, the Southwest, and the Northwest. Below normal significant fire potential is forecasted for most of Alaska and Nevada. Elsewhere, significant fire potential is expected to be normal through August.

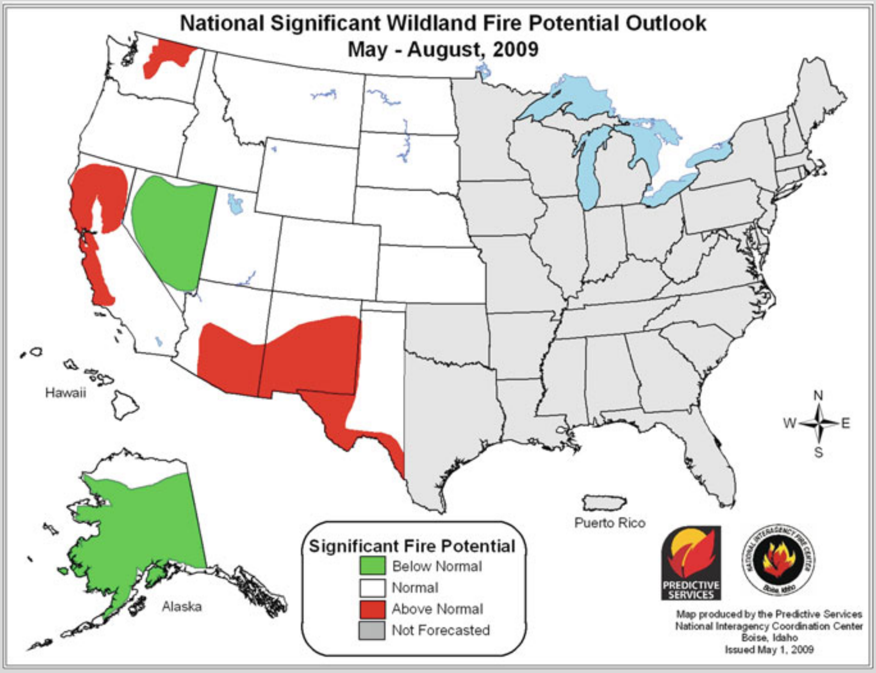


Fig. III.4.3 Significant fire potential forecast (May–August 2009)

The critical factors influencing significant fire potential for this outlook period are:

- *Drought*: Drought conditions continue to persist or intensify over portions of the West, especially in California, Nevada, and portions of Texas and New Mexico. Significant improvement has occurred over the north-central Great Plains.
- *Snowpack*: Wet fall conditions and above normal snowpack in Alaska are expected to limit fire potential. Below normal snowpack in north-central Washington and northern California along with warmer and drier than normal forecasted conditions will lead to an early snow melt and rapid drying of fuels.
- *Grassland Fuels*: Abundant new and carryover fine fuels across southern and eastern portions of the Southwest are expected to lead to an active grassland fire season. Continued moisture deficits in Nevada are expected to limit fine fuel production and associated fire spread.
- *Fire Season Onset*: Dry spring conditions in northern California are expected to cause annual grasses to cure three to five weeks early. An above normal snowpack should delay snow melt over higher elevation areas across portions of the northern Rocky Mountains, especially in northern Idaho and Montana. This will help keep fuels moist and delay the onset of fire season in these higher elevation areas.
- *Southwest Monsoon*: A robust monsoon in the Southwest should help mitigate fire potential by early July.

The brief discussion associated with the map touches on many of the key elements needed for tactical planning, not only highlighting key areas of concern, but deviations in timing of snow melting, areas of drought, timing of grass drying and so on. Seasonal outlooks for precipitation and/or temperature are important factors in assessing potential fire conditions. As the fire season progresses, the seven day outlooks available on the same website are very useful in identifying the areas of greatest fire threat.

If significant fire does break out, and it has the potential to cover an extensive area, NOAA's IMET's (incident meteorologists) are assigned to the fire manager. These specially trained meteorologists are placed at the wildfires and give weather briefings and forecasts to the incident responders and command staff (NOAA 2009). The meteorologist's forecasts ensure the safety of the operations and allow responders to plan operations, taking into account any expected changes in the weather.

The Canadian Forest Fire Danger Rating System (CFFDRS) has been an important part of forest protection operations in Canada since 1970. The ability to forecast fire weather conditions associated with the CFFDRS is critical to tactical and operational decisions and has become a routine part of fire management planning. The fire weather severity outlook is based on forecasted seasonal severity as calculated by the two principal models within the CFFDRS (Anderson et al. 2008). These are the Canadian Forest Fire Weather Index (CFFWI) and the Canadian Forest Fire

Behavior Prediction (CFFBP) system. These are described in detail by Anderson et al. (2008). See also Sect. III.4.5.(ε).

References

Anderson K, Englefield P, Carr R (2008) Predicting fire-weather severity using seasonal forecasts. Proceedings of the 7th Symposium on Fire and Forest Meteorology, Bar Harbor, 23–26 October 2007. American Meteorological Society, Boston, pp 10.6.1–10.6.5. Abstract in http://bookstore.cfs.nrcan.gc.ca/detail_e.php?Catalog=28084

Church R (2007) Tactical-level forest management models. In: Weintraub A, Romero C, Bjørndal T, Epstein R (eds) Handbook of operations research in natural resources. Springer, New York, etc, pp 343–363

Das HP, Doblas-Reyes FJ, Garcia A, Hansen J, Mariani L, Nain A, Ramesh K, Rathore LS, Venkataraman R (2010) Weather and climate forecasts for agriculture. Chapter 5 in "Guide to Agricultural Meteorological Practices", Third Edition, WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

EWC II (2003) Proceedings of the 2nd International Conference on Early Warning, Bonn, 16–18 October. http://www.ewc2.org/

GFMC (2009) Towards the development of a global early warning system for Wildland Fire. Global Fire Monitoring Center. http://www.fire.uni-frieburg.de/fwf/EWS.htm

Logan JA, Powell JA (2001) Ghost forests, global warming, and the Mountain Pine Beetle (*Coleoptera: Scolytidae*). Am Entomol 4:160–173

NIFC (2009) National InterAgency Fire Center. Details at: www.predictiveservices.nifc.gov/outlooks/outlooks.htm

NOAA (2009) Fire Weather. National Oceanic and Atmospheric Administration. http://www.noaawatch.gov/themes/fire.php

Pacific Northwest Research Station (2006) A clear picture of smoke: Bluesky smoke forecasting. Science Update 14:12. http://airfire.org/publications/non-technical/pdfs/2006_PNWUpdate.pdf

Worrall JJ (2007) Forest and shade tree pathology: disease ecology and management. http://www.forestpathology.org/mgmecol.html

III.4.4.(II) Designing and Selecting Weather Related Tactical Applications for Forest Management and Increasing Their Efficiencies

H.P. Das

A most important strategical use of climate information is in assessing suitability of land resources in terms of water availability for forest production purposes. Forests are particularly vulnerable to (and may decline rapidly under) extreme changes in water availability (either drought or water logging) (Das 2004a). It is necessary to carry out this activity during land evaluation and land planning stages to evaluate a large land area for a relatively short time. Pawitan (1993) states that soil and land resources information alone is not sufficient to assess land productivity successfully, for climate often can become a major constraint that can not easily be overcome.

Weather related tactical applications for forest management cover a wide range of practices associated with operational decisions. The agrometeorological information required in this connection includes climatological analysis of rainfall distribution in periods as short as one to five days, incoming solar radiation, wind velocity, air humidity and temperature patterns, as well as microclimatic aspects associated with planting to be adopted and with the silvicultural practices planned (De Abreu Sa 1995). In order to meet a good tactical forest management, knowledge about variability of rainfall, both in space and time, is required. Under these conditions, evaluation of rainfall in terms of probability estimates instead of arithmetic means is mandatory, since in most cases rainfall distribution becomes the key climatological element to determine land use for tree species (Retnowati 1995).

Of the three major aspects of solar radiation that can be varied on any particular site, the forest manager can control only the intensity factor. This involves the choice of harvest method (clearcutting, selective or small patch cutting) and the manipulation of light competition between crops, trees and other vegetation and between individual crop trees later on in the life of the stands (Kimmins 2005). Temperature influences the geographical distribution of different organisms and plays a major role in determining the life form and species composition in plant communities. Periodic destruction of forests by wind, the effect of wind on seed distribution, the effect of wind on the survival of planted seedlings, and wind damage to stands adjacent

H.P. Das (✉)
Retired from Indian Meteorologidal Department, Pune, India
e-mail: hpd_ag@rediffmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_61,

to clearcuts were important factors in the development of a variety of silvicultual systems and forest management tactics and strategies (Maracchi et al. 2005; Zhao et al. 2005).

From the selection of planting sites (see also Box III.4.19 for nurseries) to the scheduling of harvesting operations, nearly every tactical activity of the field forester is affected in some way by the weather. Site assessment for tactical reasons can be achieved by the definition of site-specific short term climatic conditions relevant to silvicultural systems and component selection, using variability of normals of climatic variables, climatic characterization studies (including time series, frequencies, risks, etc.), merging this information with other environmental components (e.g. soil and vegetation) using remote sensing techniques and geographical information systems (De Abreu Sa 1995). Decision making about site preparation is of paramount importance and scheduling this practice requires short-term rainfall frequencies (daily or up to 5-day totals) and operational water balance outputs using models which take into consideration the favorability of conditions for land preparation purposes (De Abreu Sa 1995).

Box III.4.19

For establishment and operation of homogeneous tree nurseries, it is important, on one hand, to time nursery operations in order to take more advantage of the local climate, while it is necessary to guarantee micrometeorological conditions compatible to the needs of the seedlings (mainly on sunlight and water). The survival of a germinated seed or a planted seedling depends on the microclimate in the immediate vicinity. The location of the nursery in this sense is an important decision since it should match microclimatic conditions required by the seedlings. Thus tree nurseries are often located near areas where the seedlings are to be transplanted so as to ensure that the climatic conditions will be similar. However, the microclimate of the nursery may be substantially different from nearby outplanting areas, particularly in desertified or hilly or mountainous regions (WMO 1993; Al-Amin et al. 2006). The forester can exert considerable control over this microclimate by such cultural activities as scarifying the soil or planting a seedling so that it is partially shaded by residual vegetation or logging debris. Through mulch manipulation new microclimates have been created in the original soil that are different from the earlier microclimates (Stigter 1984a) and these differences have been explored and exploited to create better conditions for crop germination, development, growth and ultimately yields (Doraiswamy et al. 2007). Stigter (1984b) has shown that soil temperature mitigations from mulching are due to a combination of shading and insulation effects.

For wise choices of species, it is essential to have local climate information as well as climatic requirements of species, usually based on the knowledge of the climatic conditions of a species' natural distribution, improved by information available from regions where it is found in plantations or in field trials. After the development of interpolation techniques, the accuracy with which mean climatic factors can be predicted at sites remote from recording stations (Booth 1985) has considerably improved. Methods of homoclime analysis such as CLIMSIM (climatic similarity) and BIOCLIM (bioclimatic prediction) have been devised to assist the tactical selection of tree species suitable for forestry plantations (Booth 1989, 1990, 1991).

In order to orient forest management tactics, appropriate climatic analysis (e.g. frequency distribution of variables such as rainfall, including drought spell conditions, see Box III.4.20) may be devised to schedule silvicultural operations like tree harvesting and tree removal, which are related to soil wetness to sustain logging operations. It is related also to the knowledge of other variables, including solar radiation to help tree felling timing in order to take advantages of the light environment (De Abreu Sa 1995). If non-timber products are also important, it will be necessary to have information on phenological events associated with climatic variables, in planning harvesting operations.

Box III.4.20

Information about the onset of drought conditions in a timely and reliable manner, particularly in arid and semi-arid forests, is useful in many ways to organize corrective steps in mitigating drought for forest managers. Although there are major differences in the ability to conduct meteorological forecasting and analysis of climate trends, climate information needs for managing forests in response to periodic droughts and dry spells and long-term drought are mostly similar across the world (Clayton and Elosmani 1997). The impacts of drought may also be reduced through using wider spacing in plantations and apply thinning and by including more tolerant species such as conifers (Maracchi et al. 2005). Gathering of real time forestry information from remote sensing satellites enables us to compile gross forest vegetation resources data, to plan for remedial measures for any adverse happening (e.g. drought, cyclonic storm, snowfall, etc.) much sooner than what we were able to do in the past without the facility of remote sensing (Das 2004b).

Information on microclimate features within different forest types submitted to different exploiting systems helps in tactically planning selective forest harvesting by providing a basis to decide the suitable systems to be adopted. Most studies carried out in this direction are concerned with solar radiation (mainly photosynthetically active radiation) associated to gap size, seedling growth, and vegetation dynamics, mainly in tree fall situations (Whitmore et al. 1993; Brown 1993). Several techniques are presently available to measure gap attributes and radiation patterns associated to them, as well as the structure of the succession vegetation within the gaps, including direct and indirect methods which may be applied in studies aiming to monitor selectively logged forest stands (Andrieu and Baret 1993; Cannell and

Grace 1993). Some of the main adaptive measures for forest management have been illustrated by Kellomaki (2000). These include shorter rotations and regular thinnings that in forest regions may be developed to meet the faster growth of several existing species, due to increasing precipitation and reducing drought.

In the wide-ranging forestry field, there are several areas in which tactical agrometeorological applications can be used, including: fire behaviour/danger, fire management, prescribed burning and fire effects, climate change, smoke management and air quality, and forest health and productivity (e.g. Stefanski 2004; Das 2005). To mitigate fire-related problems, forest management agencies require an early warning system to identify critical time periods of extreme fire danger in advance of their occurrence (Riebau and Qu 2005; Brady et al. 2007).

Fire is one tool that forest managers use for the sustainable tactical management of forest resources. Many forests require the regular presence of fire to maintain healthy, diverse, and productive ecosystems. The unnatural suppression of wildfire in the US has produced ecosystems with reduced biological diversity, increased susceptibility to insects and diseases, and the potential for catastrophic fires. Furthermore, due to the negative impacts of wildfire on human economic values, wildfire can not be tolerated. Therefore, a conflict exists between the ecological and practical benefits of fire to forests and the negative impacts of fire on human activities (i.e. loss of property, smoke).

To illustrate the similar management issues in wildlands across the world, controlled burning is tactically used to rejuvenate the vegetation and reduce fuel loads in the shrub lands of southwestern South Africa (Juhnke and Fuggle 1987). Additionally, Van Wilgen (1984) states that these shrub lands are strategically managed for high stream flow, nature conservation, fire hazard reduction, afforestation, grazing, tourism, and recreation. Weather plays a significant role in the fire environment. Federal fire managers in the United States recommend that fire danger rating indices, based in part on weather data, be considered part of a comprehensive set of criteria used to decide whether to fight naturally occurring forest fires or to let them burn as part of a management strategy for reducing fuel load and/or ecological purposes (Andrews and Bradshaw 1995). See also the previous sections in this Chap. III.4.

Weather is closely related to the occurrence and development of insects of forest trees. For example, the development of many insects is closely correlated with degree days summation and with other climatic variables (WMO 1993). Based on FAO (1997), insect and disease outbreaks are reported mostly for plantation forests; relatively less is known about these in native forests. It is important to be informed on the frequencies of favourable weather conditions for the development of important insects, as well as of the periods suitable for tactically successful control practices, such as spraying. Basic weather data used to interpret the forecasting of the development of insects in silvicultural systems are also tactically used in decision making regarding their control and for designing protection measures. See again also the previous sections in this Chap. III.4.

References

Al-Amin NKN, Stigter CJ, Mohammed AE (2006) Establishment of trees for sand settlement in a completely desertified environment. Arid Land Res Managem 20:309–327

Andrews PL, Bradshaw LS (1995) Fire danger rating and the go/no-go decision for prescribed natural fire. Symposium on Fire in Wilderness and Park Management: Past Lessons and Future Opportunities, Missoula, March 30–April 1 1993. General Technical Report INT-GTR-320. US Department of Agriculture, Forest Service, Ogden, pp 149–151

Andrieu B, Baret F (1993) Indirect methods of estimating crop structure from optical measurements. In: Varlet-Grancher C, Bonhomme R, Sinoquet H (eds) Crop structure and light microclimate: characterization and applications. INRA, Paris, pp 285–322

Booth TH (1985) A new method for assisting species selection. Commonw For Rev 64:241–250

Booth TH (1989) Recent developments in homoclime analysis to assist species selection. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 355–357

Booth TH (1990) A climatic analysis method for expert systems assisting tree species introduction. Agrofor Syst 10:33–45

Booth TH (1991) A global climatological audit of forest resources to assist conservation and sustainable development, Vol. 2. Proceedings of the World Forestry Congress, Paris, pp 65–70

Brady AB, de Groot WJ, Goldammer JG, Keenan T, Lynham TJ, Justice CO, Csiszar IA, O'Laughlin K (2007) Developing a global early warning system for wildland fire. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, Berlin, etc, pp 355–375

Brown ND (1993) The implications of climate and gap microclimate for seedling growth in a Bornean lowland rain forest. J Trop Ecol 9:153–168.

Cannell MGR, Grace J (1993) Competition for light: detection, measurement and quantification. Can J For Res 20:1969–1979

Clayton JL, Elosmani M (1997) Meteorological information required for managing forests in arid and semi-arid regions. CAgM Report 64, Part III, WMO/TD 728, Geneva, 7pp

Das HP (2004a) Adaptation strategies required to reduce vulnerability in agriculture and forestry to climate change, climate variability and climate extremes. In: Management strategies in agriculture and forestry for mitigation of greenhouse gas emissions and adaptation to climate variability and climate change. Technical Note 202, WMO 969, Geneva, pp 41–92

Das HP (2004b) Satellite-based agro-advisory service. In: Sivakumar MVK, Roy PS, Harmsen K, Saha SK (eds) Satellite remote sensing and GIS applications in agricultural meteorology. AGM-8, WMO/TD 1182, Geneva, pp 361–400

Das HP (2005) Agrometeorological impact assessment of natural disasters and extreme events and agricultural strategies adopted in areas with high weather risks. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 93–118

De Abreu Sa TD (1995) Definition of agrometeorological information required for forest management and exploitation in humid tropical regions: specific management decisions that require agrometeorological data. CAgM Report No. 64, Part 1B, WMO/TD 728, Geneva, 21pp

Doraiswamy PC, Hunt Jr. ER, Murty VRK (2007) Coping strategies with agrometeorological risks and uncertainties for water erosion, runoff and soil loss. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 343–354

FAO (1997) State of the world's forests 1997. UN Food and Agriculture Organization, Rome, 200pp

Juhnke SR, Fuggle RF (1987) Predicting weather for prescribed burns in the South-Western Cape, Republic of South Africa. S Afr For J 142:41–44

Kellomaki S (2000) Forestry. In: Parry ML (ed) Assessment of the potential effects of climate change in Europe. The ACACIA Report, pp 137–154

Kimmins JP (2005) Forest ecology: the ecological stage, the ecological play and the ecological actors in forest ecosystems. In: Watts SB, Tolland L (eds) Forestry handbook for British Columbia. Faculty of Forestry, University of British Columbia, Vancouver, pp 433–471

Maracchi G, Sirotenko O, Bindi M (2005) Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. Clim Change 70:117–135

Pawitan H (1993) Climatic data generation and surfacing. In: Murdiyarso D, Booth TH (eds) Evaluation of climatic and soil data for agriculture, forestry and conservation. Institut Pertanian Bogor, Bogor, Indonesia, pp 43–68

Retnowati E (1995) Definition of agrometeorological information required for forest management and exploitation in humid tropical regions: a case study from Indonesia. CAgM Report 64, Part 1A, WMO/TD 728, Geneva, pp 1–23

Riebau AR, Qu JJ (2005) Application of remote sensing and GIS for analysis of forest fire risk and assessment of forest degradation. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 335–350

Stefanski R (2004) Impact of agrometeorological applications for sustainable management of forestry. In: The impacts of agrometeorological applications for sustainable management of farming, forestry and livestock systems. CAgM Report 92, WMO/TD 1175, Geneva, pp 29–55

Stigter CJ (1984a) Mulching as a traditional method of microclimate management. Arch Meteorol Geoph Biocl Ser B 35:203–210

Stigter CJ (1984b) Traditional use of shade: a method of microclimate manipulation. Arch Meteorol Geoph Biocl Ser B 34:147–154

Van Wilgen BW (1984) Adaptation of the US fire danger rating system to Fynbos conditions. Part I. A fuel model for fire danger rating in the Fynbos biome. S Afr For J 129:61–65

Whitmore TC, Brown ND, Swaine MD, Kennedy D, Goodwin-Balley CI, Gong WK (1993) Use of hemispherical photography in forest ecology: measurement of gap size and radiation totals in a Bornean tropical rainforest. J Trop Ecol 9:131–161

WMO (1993) Guide to agricultural meteorological practices, 2nd edn, Suppl. No. 3. WMO 134, Geneva

Zhao Y, Wang C, Wang S, Tibig LV (2005) Impacts of present and future climate variability on agriculture and forestry in the humid and sub-humid tropics. Clim Change 70:73–116

III.4.5 Developing Risk Management Strategies

III.4.5.(α) Defining, Managing and Coping with Weather and Climate Related Risks in Forestry

Conrado Tobón

Risks of weather and (changing) climate in forestry are large and vary considerably in time and space. Among them, most observed risks relate to altitudinal shifts (Peters and Darling 1985; Kariuki et al. 1997; Scheffer et al. 2001; Zhao et al. 2005), changes in productivity, standing biomass and species composition and fire damages (Dixon et al. 1996; Dale et al. 2001; Flannigan et al. 2005; Scholze et al. 2006; FAO 2007), tree health and extinction (Thomas et al. 2004), and migration (Kienast et al. 1998; Stocks et al. 1998; Dale et al. 2001; Bush et al. 2004; Phillips et al. 2009; Jimenez et al. 2009). Weather and climate exert strong effects on herbivore and pathogen dynamics (Coley 1998; Matthew et al. 2000). These changes affect species composition and species richness (Kienast et al. 1998), ecosystem functions and socioeconomic values of forests (Keller et al. 2002).

Regarding migration of species, in northern Europe, Boreal forests are dominated by *Picea abies* and *Pinus sylvestris*. Under warmer conditions these species would invade tundra regions (Kirschbaum et al. 1996; Sykes and Prentice 1996), where most climate change (CC) scenarios suggest a possible enlargement of the climatic zone suitable for Boreal forests (Maracchi et al. 2005). Additionally, high risk of forest loss is shown for Canada, Central America, Amazonia, Eurasia and eastern China, with forest extensions into the Arctic and semiarid savannas (Scholze et al. 2006). Amazonian forest is at risk from drought (Saleska et al. 2007; Bonal et al. 2008; Cox et al. 2008; Phillips et al. 2009; Jimenez et al. 2009), climate-induced forest dieback, and wildfire; parts of the boreal forest may be lost; the Arctic tundra is at risk from forest invasion (FAO 2007), and most tropical forests are likely to be more affected by changes in soil water availability (Saleska et al. 2007; Bonal et al. 2008; Cox et al. 2008; Fisher et al. 2008; Phillips et al. 2009; Jimenez et al. 2009). Over time, forests may also accelerate CC, in a positive feedback, through carbon losses and changed surface energy balances (Moore 2008; Phillips et al. 2009). CC also affects primary productivity (Box III.4.21).

C. Tobón (✉)
Universidad Nacional de Colombia, Sede Medellín, Colombia
e-mail: ctobonm@unal.edu.co

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_62,

Box III.4.21

In the long term, a change in the frequency of dry years could affect tree species composition and forest diversity (Peters and Lovejoy 1992; Tilman 1996), where ecosystems with low species diversity may be most sensitive to climatic extremes (Hartshorn 1992; IPCC 2001). Climate Change (CC) affects primary productivity. Predictions by global models show that Net Primary Production (NPP) will increase fairly steadily until 2050, which is the result of forest responses to warming and increased atmospheric CO_2 concentrations (White et al. 1999; Cramer et al. 2001; Ollinger et al. 2009). However, NPP will decrease in southern Europe, the eastern United States, and many areas of the tropics and Net Ecosystem Productivity (NEP) will also decrease, due to the decline or death of tropical and temperate forests (Kienast et al. 1998; Stocks et al. 1998; White et al. 1999; Cramer et al. 2001; Ciais et al. 2005). A survey of net carbon fluxes in different forests (e.g. Amazon) revealed that extreme weather conditions push many of these ecosystems from being a net carbon sink to become a net carbon source (Ciais et al. 2005; Phillips et al. 2009; Jimenez et al. 2009).

Changes in precipitation or temperature cause changes in hydrological fluxes: warming will increase evapotranspiration and therefore reduce soil water and runoff, while decreases in precipitation will cause droughts and effects on tree vitality, with larger effects on sandy soils (Johnson et al. 2000; Smit et al. 2000; Phillips et al. 2009; Jimenez et al. 2009). However, in those regions where precipitation increases, the enhancement of surface runoff will decrease soil productivity and affect nutrient uptake by forests, linked to nutrient leaching (Smit et al. 2000). Wind storms are also considered key climate risks for forests, particularly in pre-alpine and alpine areas, as the most important natural disturbance agent in European and Canadian forests (Sykes and Prentice 1996). Although tendencies in forest risks seem to vary considerably, there is consensus that the magnitude of risks increases with the degree of CC (Scholze et al. 2006). Changes in forests will be produced at different temporal and spatial scales.

Managing forests to reduce their vulnerability to changes in weather and climate refers to adjustments in ecological, social, and economic systems in response to their effects (Devall and Parreso 1997; Smit and Pilifosova 2001; Sohngen et al. 2001). Efforts have been mainly concentrated on the following topics: (a) identify hazards and then assess their frequency of occurrence and potential impacts in order to understand the nature and extent of the associated risks, (b) determine the vulnerability of forest ecosystems and forest communities, (c) manage the forest to reduce vulnerability and enhance recovery, (d) apply new weather and climate information approaches and technologies, and (e) determine the state of the forest and identify when critical thresholds are reached (Grainger 1991; Perez-Garcia et al. 2002;

Hitz and Smith 2004; Williamson et al. 2005; Bonan 2008; Canadell and Raupach 2008).

Thus it is essential to learn from the actual difficulties faced by forest managers to cope with risk, given that there is a relatively high level of uncertainty about the effects of CC, and that its effects on forests are not well understood (Williamson et al. 2005). One approach consists in buffering forests against climate-related disturbances, like improving fire management to reduce the risk of uncontrolled wildfires or controlling invasive species, to select forest species that are better suited to coping with the predicted CC. This helps forests to evolve towards new states, better suited to altered climate (Grainger 1996; Nordhaus and Yang 1996).

Species will respond to CC through evolution, migration, extinction, or adaptation to new disturbance regimes (Nordhaus and Yang 1996). Thus these responses will be at the species level, with the movement of species ranges and the occurrence of new associations of species in space and time (Dale and Rauscher 1994; Kirschbaum 2000; Hansen et al. 2001). Indigenous farmers have developed numerous farming systems finely tuned to specific aspects of their environment. This traditional knowledge and these indigenous practices contain valuable information that should be used as a basis for improved technologies and strategies to cope with expected changes and variability (Hansen et al. 2001; Stigter et al. 2005; Williamson et al. 2005).

References

Bonal D, Bosc A, Ponton S, Goret JY, Burban B, Gross P, Bonnefond JM, Elbers J, Longoz B, Epron D, Guehl JM, Granier A (2008) Impact of severe dry season on net ecosystem exchange in the Neotropical rainforest of French Guiana. Glob Change Biol 14:1919–1933

Bonan GB (2008) Forests and climate change: forcings, feedbacks, and the climate benefits of forests. Science 320:1444–1449

Bush MB, Silman MR, Urrego DH (2004) 48,000 years of climate and forest change in a biodiversity hot spot. Science 303:827–829

Canadell JG, Raupach MR (2008) Managing forests for climate change mitigation. Science 320:1456–1457

Ciais Ph, Reichstein CM, Viovy N, Granier A, Ogee J, Allard V, Buchmann N, Aubinet M, Bernhofer Chr, Carrara A, Chevallier F, De Noblet D, Friend A, Friedlingstein P, Grunwald T, Heinesch B, Keronen P, Knohl A, Krinner G, Loustau D, Manca G, Matteucci G, Miglietta F, Ourcival JM, Pilegaard K, Rambla S, Seufert G, Soussana JF, Sanz MJ, Schulze ED, Vesala T, Valentini R (2005) European-wide reduction in primary productivity caused by the heat and drought in 2003. Nature 437:529–533

Coley PD (1998) Possible effects of climate change on plant herbivore interactions in moist tropical forests. Clim Change 32:455–472

Cox PM, Harris PP, Huntingford C, Betts RA, Collins M, Jones CD, Jupp TE, Marengo JA, Nobre CA (2008) Increasing risk of Amazonian drought due to decreasing aerosol pollution. Nature 453:212–215.

Cramer W, Bondeau A, Woodward FI, Prentice IC, Betts RA, Brovkin V, Cox PM, Fisher V, Foley JA, Friend AD, Kucharik C, Lomas MR, Ramankutty N, Sitch S, Smith B, White A, Young-Molling C (2001) Global response of terrestrial ecosystem structure and function to CO_2

and climate change: results from six dynamic global vegetation models. Glob Change Biol 7: 357–373
Dale VH, Rauscher HM (1994) Assessing impacts of climate change on forests: the state of biological modelling. Clim Change 28:65–90
Dale VH, Joyce LA, McNulty S, Neilson RP, Ayres MP, Flannigan MD, Hanson PJ, Irland LC, Lugo AE, Peterson CJ, Simberloff D, Swanson FJ, Stocks BJ, Wotton BM (2001) Climate change and forest disturbances. Biosci 51:723–734
Devall MS, Parreso BR (1997) The productivity and sustainability of southern forest ecosystems in a changing environment. In: Mickler RA, Fox S (eds) Effects of global climate change on biodiversity in forests of the southern United States. Springer, New York/Heidelberg, pp 663–682
Dixon RK, Perry JA, Vanderklein EJ, Hiol Hiol F (1996) Vulnerability of forest resources to global climate change: case study of Cameroon and Ghana. Clim Res 12:127–133
FAO (2007) Adaptation to climate change in agriculture, forestry and fisheries: perspective, framework and priorities. FAO, Rome, 32pp
Fisher RA, Williams M, Ruivo ML, de Costa AL, Meir P (2008) Evaluating climatic and soil water controls on evapotranspiration at two Amazonian rainforest sites. Agric For Meteorol 148:850–861
Flannigan MD, Amiro BD, Logan KA, Stocks BJ, Wotton BM (2005) Forest fires and climate change in the 21st century. Mitig Adapt Strat Glob Change 11:847–859
Grainger A (1991) Overcoming constraints on assessing feasible afforestation and revegetation rates to combat global climate change. In: Howlett D, Sargent C (eds) Proceedings of the Technical Workshop to Explore Options for Global Forest Management, Bangkok, 24–30 April 1991. Office of the National Environment Board, Government of Thailand/US Environmental Protection Agency, Washington, pp 196–208
Grainger A (1996) The degradation of tropical rain forest in Southeast Asia: taxonomy and appraisal. In: Eden ME and Parry JT (eds) Land degradation in the tropics. Mansell Publ, London, pp 61–75
Hansen AJ, Neilson RP, Dale VH, Flather CH, Iverson LR, Currie DJ, Shafer S, Cook R, Bartlein PJ (2001) Global change in forests: response of species, communities, and biomes. BioScience 51:765–779
Hartshorn GS (1992) Possible effects of global warming on the biological diversity in tropical forests. In: Peters RL, Lovejoy TE (eds) Global warming and biological diversity. Yale University Press, New Haven, pp 137–146
Hitz S, Smith J (2004) Estimating global impacts from climate change. Glob Environ Change 14:201–218
IPCC (2001) Climate change 2001: impacts, adaptation and vulnerabilty. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, 1005pp
Jimenez EM, Moreno FH, Lloyd J, Peñuela MC, Patino S (2009) Fine root dynamics for forests on contrasting soils in the Colombian Amazon. In: Biogeochemistry and function of Amazon forest. Biogeoscience 6:1–39
Johnson DW, Susfalk RB, Gholz HL, Hanson PJ (2000) Simulated effects of temperature and precipitation change in several forest ecosystems. J Hydrol 235:183–204
Kariuki JG, Omenda TO, Oballa PO, Kamweti DM (1997) Potential impacts of climate change on forests in Kenya. Ministry of Research, Technical Training and Technology, Nairobi, 31pp
Keller F, Lischke H, Mathis T, Mőhl A, Wick L, Ammann B, Kienast F (2002) Effects of climate, fire, and humans on forest dynamics: forest simulations compared to the paleological record. Ecol Model 152:109–127
Kienast F, Wildi O, Brzeziecki B (1998) Potential impacts of climate change on species richness in mountain forests an ecological risk assessment. Biol Conserv 83:291–305
Kirschbaum MUF, Fischlin A, Cannell MGR, Cruz RVO, Cramer W, Alvarez A, Austin MP, Bugmann HKM, Booth TH, Chipompha NWS, Cisela WM, Eamus D, Goldammer JG, Henderson-Sellers A, Huntley B, Innes JL, Kaufmann MR, Kräuchi N, Kile GA, Kokorin

AO, Körner C, Landsberg J, Linder S, Leemans R, Luxmoore RJ, Markham A, McMurtrie RE, Neilson RP, Norby RJ, Odera JA, Prentice IC, Pitelka LF, Rastetter EB, Solomon AM, Stewart R, van Minnen J, Weber M, Xu D (1996) Climate change impacts on forests. In: Watson RT, Zinyowera MC, Moss RH (eds) Climate change 1995: impacts, adaptations and mitigation of climate change: scientific-technical analyses. Cambridge University Press, Cambridge, UK, pp 95–129

Kirschbaum MUF (2000) Forest growth and species distribution in a changing climate. Tree Physiol 20:309–322

Maracchi G, Sirotenko O, Bindi M (2005) Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. Clim Change 70:117–135

Matthew P, Ayres U, Lombardero MJ (2000) Assessing the consequences of global change for forest disturbance from herbivores and pathogens. Sci Tot Environ 262:263–286

Moore PD (2008) Ecology: hope in the hills for tundra? Nature 432:159–160

Nordhaus WD, Yang ZL (1996) A regional dynamic general-equilibrium model of alternative climate change strategies. Am Econ Rev 86:741–765

Ollinger SV, Goodale CL, Hayhoe K, Jenkins JP (2009) Potential effects of climate change and rising CO_2 on ecosystem processes in northeastern US forests. Mitig Adapt Strateg Glob Change 14:101–106

Perez-Garcia J, Joyce L, McGuire AD, Xiao X (2002) Impacts of climate change on the global forest sector. Clim Change 54:439–461

Peters RL, Darling JD (1985) The greenhouse effect and nature reserves. BioScience 35:707–717

Peters RL, Lovejoy TE (1992) Global warming and biological diversity. Yale University Press, New Haven, 110p

Phillips OL, Aragão LEOC, Lewis SL, Fisher JB, Lloyd J, López-González G, Malhi Y, Monteagudo A, Peacock J, Quesada CA, van der Heijden G, Almeida S, Amaral I, Arroyo L, Aymard G, Baker TR, Bánki O, Blanc L, Bonal D, Brando P, Chave J, Alves de Oliveira AC, Dávila Cardozo N, Czimczik CI, Feldpausch TR, Freitas MA, Gloor E, Higuchi N, Jiménez E, Lloyd G, Meir P, Mendoza C, Morel A, Neill DA, Nepstad D, Patino S, Peñuela MC, Prieto A, Ramírez F, Schwarz M, Silva J, Silveira M, Sota A, Thomas G, ter Steege H, Stropp J, Vasquez R, Zelazowski P, Alvarez Dávila E, Andelman S, Andrade A, Chão KJ, Edwin T, Di Fiore A, Honorio E, Keeling H, Killeen TJ, Laurance WF, Peña Cruz AP, Pitman NCA, Núñez Vargas P, Ramírez-Ângulo H, Rudas A, Salamão R, Silva N, Terborgh J, Torres-Lezama A (2009) Drought sensitivity of the Amazon rainforest. Science 323:1344–1347

Saleska SR, Didan K, Huete AR, da Rocha HR (2007) Amazon forests green-up during 2005 drought. Science 318:612

Scheffer M, Carpenter S, Foley JA, Folke C, Walker B (2001) Catastrophic shifts in ecosystems. Nature 413:591–596

Scholze M, Knorr W, Arnell NW, Colin I (2006). A climate-change risk analysis for world ecosystems. PNAS 103:13116–13120

Smit B, Pilifosova O (2001) Adaptation to climate change in the context of sustainable development and equity. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) Climate change 2001: impacts, adaptation, and vulnerability. Intergovernmental Panel on Climate Change. Cambridge University Press, New York, pp 876–912

Smit B, Burton I, Klien RJT, Wandel J (2000) An anatomy of adaptation to climate change and variability. Clim Change 45:223–251

Sohngen B, Mendelsohn R, Sedjo R (2001) A global model of climate change impacts on timber markets. J Agric Res Econ 26:326–343

Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005) Using traditional methods and indigenous technologies for coping with climate variability. Clim Change 70:255–271

Stocks BJ, Fosberg MA, Lynham TJ, Mearns L, Wotton BM, Yang Q, Jin JZ, Lawrence K, Hartley GR, Mason JA, McKenney DW (1998) Climate change and forest fire potential in Russian and Canadian boreal forests. Clim Change 38:1–13

Sykes MT, Prentice IC (1996) Climate change, tree species distributions and forest dynamics: a case study in the mixed conifer/northern hardwoods zone of Northern Europe. Clim Change 34:161–177

Tilman D (1996) Biodiversity: population versus ecosystem stability. Ecology 77:350–363

Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BFN, Ferreira de Siqueira M, Grainger A, Hannah L, Hughes L, Huntley B, van Jaarsveld AS, Midgley GF, Miles L, Ortega-Huerta MA, Townsend Peterson A, Phillips OL, Williams SE (2004) Extinction risk from climate change. Nature 427:145–148

White A, Cannell MGR, Friend AD (1999) Climate change impacts on ecosystems and the terrestrial carbon sink: a new assessment. Glob Environ Change 9:S21–S30

Williamson TB, Parkins JR, McFarlane BL (2005) Perceptions of climate change risk to forest ecosystems and forest based communities. For Chron 81:710–716

Zhao Y, Wang C, Wang S (2005) Impacts of present and future climate variability on agriculture and forestry in the sub-humid and humid tropics. Clim Change 70:73–116

III.4.5.(β) Developing Scales and Tools for Weather and Climate Related Risk Quantifications in Forestry

Kulasekaran Ramesh

Natural disturbances play an important role in forest ecology, with effects that are highly dependent on characteristics of the specific disturbance. Climate and weather induced risks often interfere with the productivity of forests. Excessive wind, ice, and snow regularly cause major disturbances to forests in many parts of the world. The uprooted trees are susceptible to the risk of secondary damage to the surviving trees. In the last four decades, many European countries have suffered acute forest damage.

In northern and central Europe the main damage was due to windthrow, whereas in the south and Mediterranean countries, it was forest fire (FAO 1995). Forest fires cause different problems compared to those caused by windthrow. Fires destroy timber as well as all kinds of ground vegetation bringing about severe soil erosion (FAO 1995). Weather and climate related risks in forestry may be grouped into three broad categories: instant risk (immediate damage), creeping risk (slow damage) and cumulative risk (results of immediate and slow damages leading to permanent damage). This wind damage adds uncertainty for forestry planning (Quine et al. 1995).

As to instant risk, we first deal with high winds. Strong winds may have the same effect on conifers and broadleaved trees (FAO 1995). Hurricane-strength winds can cause direct damage and kill trees through uprooting and stem breakage. Very strong winds can lead to loss of branches. Trees can be permanently damaged by the bending caused by wind, ice and snow. Compression injuries may be present even in seemingly undamaged trees.

Severe bole injuries can lead to sap rot, slower growth, formation of compression wood, unusual growth rings, and intercellular voids between rings (Bragg et al. 2003). Winds often carry salt water inland, and foliage may die on trees that receive salt spray, although most affected trees will grow new leaves and recover (Gresham 2004). Pines are highly inflammable trees and on the Mediterranean coastal areas of Europe thousands of hectares of pine forests are lost each summer due to fires in combination with winds (FAO 1995).

K. Ramesh (✉)
IHBT(CSIR), Palampur, India; IISS(ICAR), Bhopal, India
e-mail: ramechek@yahoo.co.in

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_63,

As to ice and snow storms, broadleaved trees are normally more resistant to storms and snow in the late autumn and winter, due to better root systems and lack of foliage, while conifers are damaged by heavy snowfall. Ice accumulation is one of the most frequent forest disturbances in temperate regions (Irland 2000). Although ice storms can result in significant accumulation and major damages when conditions for ice formation are favorable, ice accumulation depends critically on characteristics of the layers of air and the water droplets. Small temporal or spatial differences in air temperature and droplet size frequently result in freezing rain mixed with sleet, snow, or nonfreezing rain, which substantially complicates area-specific forecasting of ice formation and accumulation (Heidorn 2001).

Glaze storms are a common meteorological phenomenon over much of North America causing significant damage to many forests. In the central and southern Appalachians, glaze storms have been a major frequent natural disturbance of the forest and played an important role in shaping local vegetation (Warrillow 1999). In all these works, risk quantifications do not go beyond useful but often limited statistics on occurrence of disturbing factors and on various categories of damages and resiliences, but it sometimes includes resistance scales (Warrillow 1999).

Under creeping risks, drought may be described as a chronic natural disaster characterized by prolonged and abnormal water shortage. The severity of drought in forest ecosystems can be measured by a number of indices, each having its own merits and demerits. Each index measures the drought with certain assumptions. The material below was for a good part modified and simplified from http://www.dnr.sc.gov/drought/index.php?pid=1.

As early as the 1960s, Palmer (1965) developed an index now called Palmer Drought Severity Index (PDSI, Table III.4.1), based on a water balance accounting scheme. It was designed to detect the beginning and end of drought and to formulate a drought severity index. This index is widely recognized as effective in understanding long-term drought. During the growing season, the National Oceanic and Atmospheric Administration (NOAA) updates this index every week. Its value describes a range accommodating both extremes of wetness and drought. A modified PDSI was developed by Heddinghaus and Sabol (1991) from the sum of the wet and dry terms weighted by the "probability" values.

McKee et al. (1993) have introduced the Standardized Precipitation Index (SPI) to quantify the precipitation deficit at different time scales (Table III.4.2). This was developed to categorize the observed rainfall as a standardized departure with respect to a rainfall probability distribution function. It indicates how precipitation for any given duration (1 month, 2 months, etc) at a particular observing site compares with the long time precipitation record at the same time of the same duration (Edwards and McKee 1997).

This is entirely based on the concept of standardized precipitation, which is the difference between total precipitation for some period of time and historical mean total precipitation for the same period divided by the standard deviation. The use of flexible time scales, obtained by accumulating precipitation for a specific period of time, is a peculiarity of this index, as different time scales are applied to different

Table III.4.1. Palmer Drought Severity Index classes for wet and dry periods

Palmer index	Class
4.0 or more	Extremely wet
3.0 to 3.99	Very wet
2.0 to 2.99	Moderately wet
1.0 to 1.99	Slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to −0.49	Near normal
−0.5 to −0.99	Incipient dry spell
−1.0 to −1.99	Mild drought
−2.0 to −2.99	Moderate drought
−3.0 to −3.99	Severe drought
−4.0 or less	Extreme drought

Table III.4.2. SPI drought severity classes for wet and dry periods (McKee et al. 1995)

SPI	Class
2.0 or more	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
0.99 to −0.99	Near normal
−1.0 to −1.49	Moderate drought
−1.5 to −1.99	Severe drought
−2.0 or less	Extreme drought

droughts (McKee et al. 1995; Guttman 1999). This provided better scales of wetness and dryness than the PDSI. Though Chaudhari and Dadhwal (2004) used this index for agricultural crops in a region, this can also be utilized for forestry risk quantification. They computed SPIs at various time scales with Pearson's Type III distribution.

A Precipitation Concentration Index (PCI, DeLuis et al. 2000) was used to study the heterogeneity of rainfall over an area for rubber cultivation and was modified slightly by Raj and Dey (2004). A classification is in Table III.4.3.

Table III.4.3. PCI values and classification

Rainfall distribution	PCI values
Uniform rainfall distribution	< 10
Seasonal rainfall	11–20
Substantial monthly variability	> 20

A Palmer Z-index is also used in the Czech Republic, which characterizes the immediate (for a given week/month) conditions of weather. As a moisture anomaly index, the Z-Index is calculated from the difference between the actual precipitation in the month and precipitation that is climatologically appropriate for existing condition, weighted by a climate characteristic K (Rhee 2007). Recently, Ghulam et al. (2007a) have developed a Perpendicular Drought Index (PDI) using spectral space derived from reflectance of near infrared and red wavelengths.

Somewhat later, Ghulam et al. (2007b) developed an improved drought monitoring method, the Modified Perpendicular Drought Index (MPDI), by introducing a vegetation fraction, which takes into account both soil moisture and vegetation growth. Both these indices provided similar results for bare soil surfaces, especially in the early stages of vegetation growth, but the MPDI demonstrated a much better performance in measuring vegetated surfaces. The MPDI has the potential to provide a simple and real-time drought monitoring method in the remote estimation of drought phenomena.

While the SPI is based solely on precipitation data, the PDSI (known operationally also as the Palmer Drought Index), attempts to measure duration and intensity of long-term drought inducing circulation patterns: http://lwf.ncdc.noaa.gov/oa/climate/research/prelim/drought/palmer.html.

Palmer Z-indices (measuring short-term drought on a monthly scale) are based on precipitation and temperature data and on the available water content of the soil (Dubrovsky et al. 2005). Relative SPI and PDSI (rSPI and rPDSI) have also been developed by Dubrovsky et al. (2009). The PDSI exhibited the widest spectrum of drought conditions across Czechia (Dubrovsky et al. 2009).

As we have seen in previous sections of this Chap. III.4, drought and fire have direct positive relations (also e.g. Bai 2009 for China). Prolonged drought leads to fire catastrophes in forests. Several indices are available to quantify these cumulative risks in forestry. The Keetch and Byram Drought Index (KBDI) (Keetch and Byram 1968) is a function of the maximum air temperature and the total rainfall (for the past 24 h). This index may be computed for a specified mean annual rainfall. The authors have also made five tables (mean annual rainfall of 10–19, 20–29, 30–39, 40–59 and >60 in.) with drought factors for each table. To compute the KBDI drought index, the drought factor is to be decided. The detailed computation can be found in Keetch and Byram (1968).

The KBDI is a measure of meteorological drought, describes the soil moisture deficit and is used to assess wildfire potential as part of the US national Fire Danger Rating System (FDRS, Haines et al. 1976; Heim 2002). An example is in Table III.4.4. In the southeast, the KBDI is used as a stand-alone index for assessing fire danger (Johnson and Forthum 2001). The initialization of the KBDI usually involves setting it to 0 after a period of substantial precipitation (Fujioka 1991). The higher the value, the higher is the drought severity and vice versa. An examples is in Table III.4.5.

The KDBI provides fire control managers a continuous reference scale for estimating the dryness condition of the upper soil as well as the covering layer. The KBDI has been widely used in wildfire monitoring and prediction (Heim 2002). For almost 5 years the Integrated Forest Fire Management (IFFM) Project has used the KBDI for Fire Danger Rating in East Kalimantan (Indonesia) on an operational basis. A revised index was also developed by Deeming (1995). The index

Table III.4.4. Fire danger rating classes

Rating scale	Values
Low	Below 999
Moderate	1,000–1,499
High	1,500–1,750
Extreme	1,750–2,000

Table III.4.5. KBDI drought severity classes (Melton 1988)

KBDI	Class
0–150	Upper soil and duff layer are very wet. Fire can be easily controlled by normal practices
150–300	Pine and hardwood stumps can ignite but the fire hardly goes below ground. Snags may cause escaped fires but can be controlled by standard control tactics
300–500	Heavier fuel complexes such as stumps ignite easily in this stage and fire intensity increases significantly. Additional personnel and equipment as well as increased mop-up and patrol activities are required
500–700	Fire behavior tends to become unpredictable and more urban interface type fire starts to occur
700 and more	Every burning activity should be prohibited until the KBDI levels go down below 500

was originally divided into three fire danger classes. For practical reasons and with the focus on the potential end user concessionaires, the fire danger rating class "extreme" will be added to the classes (Table III.4.4).

The validity of the KBDI for fire was studied (Dolling et al. 2003) through its relationship with Total Acres Burned (TAB), for the four major islands of Hawaii using a Spearman rank correlation. As the KBDI increased, the TAB values also increased and vice versa. This helped to establish that the KBDI is good in discriminating groups of high from low TAB.

More information on other drought scales is available at http://www.cpc.ncep.noaa.gov/index.html and http://www.uvm.edu/∼ldupigny/sc/.

Nesterov (1949) developed a simple Fire Danger Rating Index which is based on days without rain, dry bulb temperature and dew point temperature (based on relative humidity and temperature). The Canadian Forest Fire Weather Index (CFFWI), see also Sect. III.4.4.(I), is used by the Republic Hydrometeorological Service of Serbia (Anonymous 2009). For forest fire risks see also Sect. III.4.5.(γ).

References

Anonymous (2009) Application of meteorology in forest fire protection. www.hidmet.sr.gov.yu/podaci/dokumenti_eng/FWI_Engleski.pdf

Bai Renhai (2009) Analysis and forecast for weather classification of forest-fire over North eastern China. www.ecpc.ucsd.edu/projects/RSM/RSM2004/presentation/rsm2004-3.7-Bai.ppt

Bragg DC, Shelton MG, Zeide B (2003) Impacts and management implications of ice storms on forests in the southern United States. For Ecol Manag 186:99–123

Chaudhari KN, Dadhwal VK (2004) Assessment of drought-2002 on the production of major kharif and rabi crops using standardized precipitation index. J Agrometeorol 6(Spl. issue): 10–15

Deeming JE (1995) Development of a fire danger rating system for East Kalimantan. Integrated Forest Fire Mangement Project Report. Contract No. 1-60134345. http://www.iffm.or.id

DeLuis M, Raventos J, Gonzalez-Hidalgo JC, Sanchez JR, Cortina J (2000) Spatial analysis of rainfall trends in the region of Valencia (East Spain). J Climatol 20:1451–1469

Dolling KP, Pao-Shin Chu, Fujioka F (2003) The validity of the KEETCH/BYRAM drought index in the Hawaiian islands. www.ams.confex.com/ams/pdfpapers/65943.pdf

Dubrovsky M, Hayes M, Trnka M, Svoboda M, Wilhite D, Zalud Z, Semeradova D (2005) Application of drought indices for the changed climate. http://adsabs.harvard.edu/abs/2005 AGU FM. H3387D

Dubrovsky M, Svoboda MD, Trnka M, Hayes MJ, Wilhite DA, Zalud Z, Hlavinka P (2009) Application of relative drought indices in assessing climate-change impacts on drought conditions in Czechia. Theor Appl Climatol 96:155–171

Edwards DC, McKee TB (1997) Characteristics of 20th century drought in the United States at multiple time scales. Department of Atmospheric Science, Colorado State University, Climatology, Report Number 97–2, Fort Collins, 155pp

FAO (1995) Acute forest damage manual. Managing the impact of sudden and severe forest damage. Food and Agriculture Organization, Economic Commission for Europe, International Labour Organization, Rome, etc. www.unece.org/timber/storm/manual chap1.pdf

Fujioka FM (1991) Starting up the Keetch-Byram drought index. Extended Abstract, 11th Conference on Fire and Forest Meteorology, Missoula, pp 74–80

Ghulam A, Qin Q, Zhan Z (2007a) Designing of the perpendicular drought index (PDI). Environ Geol 52:1045–1052

Ghulam A, Qin Q, Teyip T, Li Z (2007b) Modified perpendicular drought index (MPDI): a real-time drought monitoring method. ISPRS J Photogramm Remote Sensing 62: 150–164

Gresham CA (2004) Loblolly pine saplings affected by Hurricane Hugo retained growth. In: Connor KF (ed) Proceedings of the 12th Biennial Southern Silvicultural Research Conference, USDA, Forest Service, Southern Research Station, Asheville, pp 196–198

Guttman NB (1999) Accepting the Standandardized Precipitation Index: a calculation algorithm. J Am Water Resour Assoc 35:311–322

Haines DA, Von Johnson J, Main WA (1976) An assessment of three measures of long term moisture deficiency before critical periods. Research Paper NC-131, USDA, Forest Service, North Central Forest Experiment Station, St. Paul, 102pp

Heddinghaus TR, Sabol P (1991) A review of the Palmer Drought Severity Index and where do we go from here. Proceedings of the 7th Conference on Applied Climatology, American Meteorological Society, Salt Lake City, 10–13 September, pp 242–246

Heidorn KC (2001) Ice storms: Hazardous beauty. http://www.islandnet.com/∼see/weather/elements/icestorm.htm

Heim RR (2002) A review of twentieth century drought indices used in the United States. Bull Am Meteorol Soc 83:1149–1165

Irland LC (2000) Ice storms and forest impacts. Sci Tot Environ 262:231–242

Johnson MB, Forthum G (2001) Spatial mapping of KBDI for the southeast United States. Proceedings of the 4th Symposium on Fire and Forest Meteorology, American Meteorological Society, Reno, 13–15 November, Preprints, pp 64–65

Keetch JJ, Byram GM (1968) A drought index for forest fire control. Res. Pap. SE-38. USDA, Forest Service, Southeastern Forest Experiment Station, Asheville, 35pp

McKee TB, Doeskin NJ, Kleist J (1993) The relationship of drought frequency and duration to time scales. Proceedings of the 8th Conference on Applied Climatology, American Meteorological Society, Boston, 17–22 January, pp 179–184

McKee TB, Doeskin NJ, Kleist J (1995) Drought monitoring with multiple time scales. Proceedings of the 9th Conference on Applied Climatology, American Meteorological Society, Boston, January 15–20, pp 223–236

Melton M (1988) The Keetch-Byram Drought Index: a guide to fire conditions and suppression problems. Forest Protection Bureau, Florida Division of Forestry, Tallahassee. http://flame.fl-dof.com/Env/RX/kbdisuppress.html

Nesterov VG (1949) Combustibility of the forest and methods for its determination. USSR State Industry Press, Moscow (in Russian), 190pp

Palmer WC (1965) Meteorological drought. Research Paper No. 45, Weather Bureau, Washington, 58pp

Quine CP, Coutts MP, Gardiner BA, Pyatt DG (1995) Forests and wind: management to minimise damage. Forestry Commission Bulletin 114, HMSO, London, 24pp

Raj S, Dey SK (2004) Spatial analysis of rainfall variability over the northeast with respect to rubber cultivation. J Agrometeorol 6(Spl. issue):52–57

Rhee J (2007) Dynamic drought index for basins in North and South Carolina. http://www.dnr.sc.gov/drought/index.php

Warrillow MP (1999) Ecological impact of glaze storm damage in an Appalachian oak forest. M.Sc. thesis submitted to Virginia Polytechnic Institute and State University. www.scholar.lib.vt.edu/theses/available/etd-031999-145749/unrestricted/etd.PDF

III.4.5.(γ) Improving Weather and Climate Related Risk Assessments in Forestry

Kulasekaran Ramesh

Forest risk management for minimizing climate and weather induced damage requires assessing the current damage and predicting the future risks as accurately as possible. The main causes of acute forest damage are strong winds, fires, insect attacks, pollution and flooding (FAO 1995), out of which our interest here lies in wind (Box III.4.22), fire and flooding effects. Gadow (2000) has made an excellent review on "Evaluating risk in forest planning models".

Box III.4.22

It is known that forests are more or less susceptible to strong winds depending on their site conditions. Wind storm damage can be modeled with conventional statistical methods such as regression models or standard nonparametric methods but these are inefficient or even inappropriate for the tail of the distribution. In view of these shortcomings, within the framework of statistical extreme value theory Bengtsson and Nilsson (2007) have developed a Poisson point process model that can be used to describe these storm damage events.

An analytical model was developed by Holland et al. (2006) to describe patterns of downed trees produced by tornadic winds. The authors used a combined Rankine vortex of specified tangential and radial components to describe a simple tornado circulation. Patterns of windfall are computed and are compared to reveal three basic damage patterns: cross-track symmetric, along-track asymmetric and criss-cross asymmetric. These patterns are shown to depend on forward speed, radial speed, and tree resistance. This model may be useful in assessing storm characteristics from damage patterns observed in forested areas.

Hanewinkel et al. (2004) examined the Artificial Neural Network (ANR) technique to model wind damage to forests. They showed that this improves

K. Ramesh (✉)
IHBT(CSIR), Palampur, India; IISS(ICAR), Bhopal, India
e-mail: ramechek@yahoo.co.in

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_64,

classification of forests susceptible to wind damage compared to a logistic regression model. Using the same technique, later Hanewinkel (2005) developed a methodological approach for risk assessment at the forest division level, especially in secondary coniferous forests. Experiences with the application of this method were made by predicting the risk for storm damage within one decade for a state forest containing 139 divisions (around 4,000 ha).

In order to mitigate the effects of natural hazards on forests, scientific management is an absolute necessity. The pre-operational and real-time management are to be considered seriously. First we need methods able to forecast the risk for each forest location, after which assessment management options may be thought off. Fiorucci et al. (2005) presented a general framework for forest fire risk management in pre-operational and real-time phases.

Risk assessment may be based on an approach including different forms of modeling (probabilistic, semi-probabilistic or determinist), data and tools (Blanchi et al. 2002). Risk assessment is generally probabilistic and this can be defined as estimating the probabilities of occurrence of certain hazardous events within a specified time period and in a specified context. Such an assessment often proceeds by reducing a particular complex system to simpler components, followed by the fitting and validation of stochastic (random probability distribution) models associated with the components.

Typically large doses of substantive subject matter are required in such modeling and data analysis projects (Brillinger et al. 2003). The current methods of wind damage risk assessment were classified as (a) observational/empirical methods, (b) statistical methods and (c) mechanistic methods. Kamimura and Norihiko (2007) concluded from case studies in Japan that the mechanistic methods would be one of the most powerful approaches to estimate the possibility of future wind damage risk with changes of stand conditions.

Forest fires are part of the ecosystem, but they become a risk when by their frequency, intensity and/or distribution they destroy forest beyond what fits management purposes and threatens men and their activities (Blanchi et al. 2002). One of the problems associated with deficient rainfall is that of wildfires. Fire risk is the result of prolonged drought (see Sect. III.4.5.(β)). Extreme high temperatures can help to generate drought conditions favourable for forest fire ignition under specified conditions. The other weather parameters influencing the fire risk are precipitation and relative humidity. For heat waves, hazard is defined by particular meteorological conditions, based primarily on temperature.

The HUMIDEX (combination of temperature and humidity) indicator has been adopted in some studies. This index is explained in the Wikipedia: http://en.wikipedia.org/wiki/Humidex. For example, the number of days when

HUMIDEX exceeded 35 for the summer of 2003 and corresponding exposure may be found.

The European Potential Drought Hazard Map describes the likelihood of soil moisture deficits for 25 Member States of the European Union plus the two accession countries Romania and Bulgaria on the administrative NUTS-3 level (Lavalle et al. 2006). Related forest fire risk mapping has been done for the European Union as well. Two main indicators have been proposed: the fire density (fire frequency normalized upon time and space) and burned forest fraction (the forest burned area normalized upon time and forest land area). The two derived maps provide an estimate of the spatial distribution of fire hazard in EU and currently cover 15 EU countries among the most prone to forest fires (Lavalle et al. 2006). In tropical countries like Malaysia, forest fires are a very common natural disaster. Pradhan et al. (2007) have made an effort to map the forest areas for susceptibility based on remote sensing and geographical information systems at Sungai Karang and Raja Muda Musa Forest Reserve, Selangor, Malaysia.

In recent years the ability to predict forest damage as a result of wind has become increasingly important. Wind not only causes extensive damages to trees in many parts of the world, it also has more subtle effects on the growth and morphology of trees and forest ecology as well. It is believed that the risk of further and stronger storms is increasing (Jiaojun et al. 2004). Wind damage can be a major ecological disturbance factor from northern boreal forests to tropical rain forests (Gardiner and Peltola 1996).

A number of tools have been developed to predict windthrow risk to forest stands over the years (Elling and Verry 1978; Peltola and Kellomaki 1993; Mitchell et al. 2001; Mickovski et al. 2005). Peltola et al. (1999) presented a mechanistic model for assessing the risk of wind and snow damage to single trees and stands of scots pine, norway spruce and birch. The model predicted the critical turning moment and wind speed at which the trees will be uprooted or break at forest margins.

Gardiner and Quine (2000) discussed the ForestGALES wind risk model (see also http://www.forestresearch.gov.uk/forestgales) used to demonstrate the deterministic/probabilistic approach to risk assessment. The importance of quantitative risk estimation is illustrated by model output comparing a range of silvicultural strategies and site characteristics. Mathematical models provide an opportunity for objectively calculating the risks to forests and will in the future allow forest managers to make informed decisions about how best to manage forests in order to minimise these risks. ForestGALES calculates the probability of *average trees* being damaged within a stand.

Damage to the average tree will by implication mean that the stand as a whole will be substantially damaged (Gardiner et al. 2004). It enables forest managers to estimate the probability of wind damage to conifer stands (Nicoll et al. 2004). Considering the damage caused by two windstorms, "Vivian" and "Lothar", in the Swiss forest, Casals et al. (2003) used Geographical Information Systems (GISs) to assess the risks to Swiss forests by windstorms in terms of terrain risk zones. Using the

CROSSTAB function of IDRISI software, the percentage of forest damage caused by wind storms was identified for each terrain factor.

Windthrow is a natural phenomenon affecting forests throughout British Columbia. Every year hundreds of hectares of trees are blown over in uncut stands and along cutblock boundaries and road allowances. At recurrence intervals of 10–20 years, thousands of hectares of forest are wind thrown by gale or hurricane force winds. The Forestry Commission in the United Kingdom has developed a quantitative windthrow hazard classification scheme for identifying where wind damage is most likely to occur (Stathers et al. 1994). Schmoeckel and Kottmeier (2008) suggested a method to assess the storm damage in the Black Forest caused by the winter storm.

Statistical models like logistic regression models are limited in ability to predict damages to forest stands. An airborne survey of the Black Forest as affected by the winter storm "Lothar" in 1999 was performed by means of a color line scanner with a charge coupled device sensor. This produced the Normalized Difference Vegetation Index (NDVI) as a measure of the damage in previously intact forest areas. The camera data, height data from a digital elevation model, land use information, and soil data were processed with GIS to derive a relationship of the damage pattern with the characteristics of the local orography and soil types. The described method for automatic detection of storm damage areas from airborne gained vegetation data (NDVI) is suitable for damage areas larger than 1.5 ha.

Flood events, depending upon the magnitude, can produce destructive effects on forestry, as the force may topple tree stands. Related secondary impacts from flood may expose root systems to stress, besides rendering them more vulnerable to windthrow. A GIS database has been designed and developed to spatially represent the three components of flood risk in the European Union for flood risk mapping (Lavalle et al. 2006).

References

Bengtsson A, Nilsson C (2007) Extreme value modelling of storm damage in Swedish forests. Nat Haz Earth Syst Sci 7:515–521. http://hal.archives-ouvertes.fr/docs/00/29/94/46/PDF/nhess-7-515-2007.pdf

Blanchi R, Jappiot M, Alexandrian D (2002) Forest fire risk assessment and cartography – a methodological approach. In: Forest fire research and wildland fire safety. Proceedings of the 4th International Conference on Forest Fire Research; 2002 Wildland Fire Safety Summit, Luso, Coimbra, 18–23 November. http://www.cababstractsplus.org/abstracts/Abstract.aspx?AcNo=20033044432

Brillinger DR, Preisler HK, Benoit JW (2003) Risk assessment: a forest fire example. www.fs.fed.us/psw/publications/preisler/psw_2003_preisler001_ims.pdf

Casals P, Beniston M, Goyette S (2003) Windstorms and risk analysis related to forest damage in the Swiss alps using GIS techniques. www.ams.confex.com/ams/pdf papers/79937. pdf

Elling AE, Verry ES (1978) Predicting wind caused mortality in strip cut stands of peatland spruce. For Chron 54:249–252

FAO (1995) Acute forest damage manual. Managing the impact of sudden and severe forest damage. Food and Agriculture Organization, Economic Commission for Europe, International Labour Organization, Rome. www.unece.org/timber/storm/manual pdf iii. preface

Fiorucci P, Gaetani F, Minciardi R, Trasforini E (2005) Natural risk assessment and decision planning for disaster mitigation. Adv Geosci 2:161–165

Gadow K (2000) Evaluating risk in forest planning models. Silva Fenn 34:181–191

Gardiner BA, Peltola H (1996) The development and testing of models for predicting the critical wind speed to damage trees. Poster Presented at Second International Workshop on Disturbance Dynamics in Boreal Forests, Quebec, 26–30 August. http://gis.joensuu.fi/storms/abstract.htm

Gardiner BA, Quine CP (2000) Management of forests to reduce the risk of abiotic damage, a review with particular references to the effects of strong winds. For Ecol Manage 135:261–277

Gardiner B, Suárez J, Achim A, Hale S, Nicoll B (2004) Forest GALES version 2. A PC-based wind risk model for British forests. Forestry Commission, UK. www.forest-research.gov.uk/pdf/FORESTGALES2_manual_2004.pdf/$FILE/FORESTGALES2_manual_2004.pdf

Hanewinkel M (2005) Neural networks for assessing the risk of windthrow on the forest division level: a case study in southwest Germany. Eur J For Res 124:243–249

Hanewinkel M, Zhou W, Schill C (2004) A neural network approach to identify forest stands susceptible to wind damage. For Ecol Manage 196:227–243

Holland AP, Riordan AJ, Franklin EC (2006) A simple model for simulating tornado damage in forests. J Appl Meteorol Climatol 45:1597–1611

Jiaojun Z, Zugen L Xiufen L, Matsuzaki T, Gonda Y (2004) Review: effects of wind on trees. J For Res 15:153–160

Kamimura K, Norihiko S (2007) A review of strategies for wind damage assessment in Japanese forests. J For Res 12:162–176

Lavalle C, Barredo JI, De Roo A, Feyen L, Niemeyer S, Camia A, Hiederer R, Barbosa P (2006) *Pan* European assessment of weather driven natural risks. www.ec.europa.eu/regional_policy/conferences/od2006/doc/presentations/c/lavalle_10c14.pdf

Mickovski SB, Stokes A, Van Beek LPH (2005) A decision support tool for windthrow hazard assessment and prevention. For Ecol Manage 216:64–76

Mitchell SJ, Hailemariam T, Kulis Y (2001) Empirical modeling of cutblock edge windthrow on Vancouver Island, Canada, using stand level information. For Ecol Manage 154:117–130

Nicoll B, Achim A, Gardiner B (2004) ForestGALES decision support system will be adapted for use across the North Sea Region. www.svo.se/episerver4/-document/vg/Skaraborg/Babs/ForestGALESposter_STORMRISK2.pdf

Peltola H, Kellomaki S (1993) A mechanistic model for calculating windthrow and stem breakage of Scots pines at stand edge. Silva Fenn 27:99–111

Peltola H, Kellomäki S, Väisänen H, Ikonen VP (1999) A mechanistic model for assessing the risk of wind and snow damage to single trees and stands of Scots pine, Norway spruce and birch. Can J For Res 29:647–661

Pradhan B, Hairi MD, Suliman BN, Arshad Bin Awang M (2007) Forest fire susceptibility and risk mapping using remote sensing and geographical information systems (GIS). Disas Prev Manage 16:344–352

Schmoeckel J, Kottmeier C (2008) Storm damage in the Black Forest caused by the winter storm "Lothar" – Part 1: airborne damage assessment. Nat Haz Earth Syst Sci 8:795–803

Stathers RJ, Rollerson TP, Mitchell SJ (1994) Windthrow handbook for British Columbia forests. Working Paper 9401. Ministry of Forests, Victoria, 33pp

III.4.5.(δ) Designing and Communicating Improvements in Forestry Applications of Risk Information Products

Kees Stigter

This subject is approached through a case study illustrating what is possible these days in industrial countries. Sanborn (2007a) provides a general description of the methods and science used to develop a Wildfire Risk Information Product (WRIP) for California. It provides the necessary scientific reference and methods description required by fire professionals to properly utilize the product for both planning and operational purposes. The model used to develop the product has been successfully applied in 13 other states prior to California. Details are in the illustration material of Box III.4.23. For California, enhancements were incorporated into the model to accommodate consideration of severity of damage in deriving final hazard ratings.

Box III.4.23

A number of secondary outputs are included in the WRIP. These datasets represent intermediate outputs derived in the model. They provide additional detail that can aid fire professionals in evaluating risk and determining actions for fire planning or operations. These outputs include:

- Fire occurrence – likelihood of a fire igniting based on historical ignition locations
- Rate of spread
- Flame length
- Fire type (crown fire potential)
- Surface fuels
- Canopy characteristics
- Historical fire perimeters – location of historical fire areas

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_65,

Fire behavior analysis was conducted as a key component of the WRIP model. Fire behavior outputs are available on a percentile weather basis (low, moderate, high, extreme). This provides maximum flexibility in analyzing threat, susceptibility and hazard (Sanborn 2007a).

Specifically designed to meet Community Wildfire Protection Plan (CWPP) development requirements, quantifiable risk measures of wildfire threat, historical fire occurrence, and fuel hazards are provided. The California WRIP is a set of thematic maps that describe the level of wildfire risk on a per pixel basis for all of California. This product satisfies a requirement to help fire prevention specialists, wildland-urban interface coordinators, and fire planners develop prevention and mitigation activities to reduce the risk to the public and property (Sanborn 2007b). Figure III.4.4 shows an example of fire perimeters in Los Angeles and Orange County, USA, on 27 October 2007 (Sanborn 2007c).

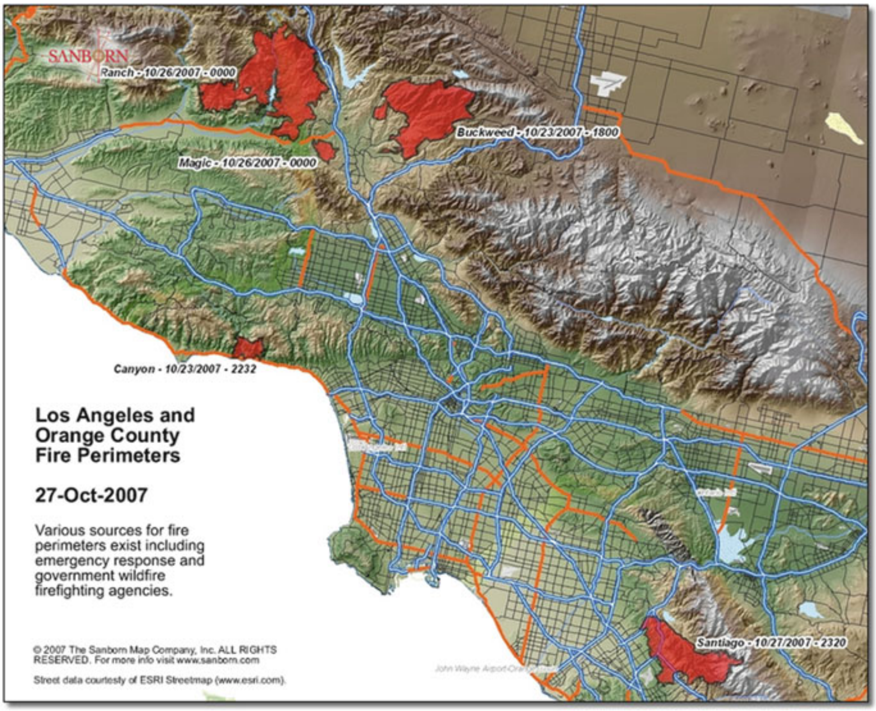


Fig. 1 III.4.4. Fire perimeters in Los Angeles and Orange County (USA) on 27 October 2007

WRIP model outputs are highly dependent on key input data layers, such as surface fuels, canopy fuels, historical fire ignition data and fire occurrence areas. As such, special care is taken in compiling the best available data using publicly available data sources. For example, multiple data sources exist for surface fuels (Sanborn 2007a). Future enhancements to the product will incorporate change detection to provide more up to date and accurate fuel and land cover data.

The WRIP incorporated modeling for the following key characteristics (Sanborn 2007a):

- Topography
- Historical weather observations
- Weather influence zones and percentile weather
- Surface fuels
- Canopy fuels
- Historical fire ignitions
- Historical fire perimeters
- Fire behavior analysis
- Rates of spread versus final fire size
- Severity of damage and probability of loss to average structures
- Urban versus wildland land use delineation

Three primary measures of risk were developed using a weighted function where a greater weight is applied to susceptibility in order to reflect the higher potential for loss if a fire were to occur, regardless of historical ignitions. The WRIP is comprised of the following primary outputs:

- Wildfire threat: annual likelihood that a wildfire occurs within or spreads into an area
- Wildfire susceptibility: probability of severe damage given a fire occurs nearby
- Wildfire hazard: annual likelihood of severe damage to an average structure accounting for both, susceptibility and threat.

Threat and Hazard are classified from Low to Extreme representing fire return periods (i.e. Extreme is less than 20 years). Susceptibility is classified in Low to Extreme classes representing a probability value from 0 to 1. Secondary outputs are mentioned in Box III.4.23.

The case study treated above is typically for commercial agrometeorological services in developed countries. For developing countries an Australian approach would make a lot of sense, where CSIRO is developing profitable systems for traditionally marginal forestry regions by providing the following information (CSIRO 2008):

- Tree breeding for marginal environments, including the Australian Low Rainfall Tree Improvement Group (ALRTIG).
- Commercial environmental forestry.
- Production of seed for growers.
- Integrating trees into farms for dryland salinity management.
- Landscape hydrology and implications for siting of plantations.
- Irrigation management.

- Groundwater uptake by plantations.
- Identification of environmental limitations for key tree species – matching species to specific sites and predicting growth rates.

References

CSIRO (2008) Developing profitable systems for dryland farm forestry. http://www.csiro.au/science/DrylandForestrySystems.html

Sanborn (2007a) California wildlife risk information product. Description of technical methods. www.sanborn.com/pdfs/California%20WRIP%20Methods%20Description.pdf

Sanborn (2007b) California wildfire risk information product. www.sanborn.com/products/marketsheets/WRIP_042507.pdf

Sanborn (2007c) Wildfire risk information product. http://www.sanborn.com/solutions/wrip.asp

III.4.5.(ε) Improving Coping Strategies with Weather and Climate Related Risks in Forestry Including the Improved Use of Insurance Approaches

Kees Stigter and Kulasekaran Ramesh

It follows from the work of the IPCC (2007) that climate changes and poverty developed a gradual and sustained deterioration of the environment with an effect on agriculture, forestry, ecosystems, water resources, public health, industry, institutions and societies. On their side, African states in the framework of The New Partnership for Africa's Development (NEPAD) worry about the extinction and loss of forests due to industrial timber exploitation, firewood collecting, and slash and burn agriculture etc. (OAA 2008).

In an introductory overview of crop insurance and forestry insurance (FAO 2005), two fairly new insurance products were recently presented: the first based on insuring a level of crop revenue (including forests), and the second where insurable damage is determined on the basis of an index derived from data external to the insured farm (for examples see Box III.4.24). While most of the example material is taken there from agriculture and forestry in developed countries, the basic target group are those concerned with coping with environmental crop and forest risks in developing country. See also Box III.2.24 in Sect. III.2.5.(ε) and Box III.3.25 in Sect. III.3.5.(ε) for extensively discussed examples from Africa, and the bulk text of Sect. III.3.5.(ε) for relevant discussions.

Box III.4.24

Fire danger indices have been developed in many countries to assess the risk for dangerous fires and their behavior. Systems and indices developed include the Canadian Forest Fire Weather Index (CFFWI) System (Canada), *Orieux*

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia;
Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_66,

Index (France), *Carrega* Index (France), Numerical Index (France), IREPI Index (Italy), Portuguese Index, Icona Index (Spain), Fire Danger Rating System (FDRS, USA), *Drought Mac-Arthur* Index (Australia), *Angstrom* Index (Sweden), *Lourenço* Index (Portugal), the *M-68*Forest Fire Danger Index and the Experimental Grassland Fire Danger Index (Germany) as well as the Monte Alegre Formula (FMA, Brazil) (Keenan et al. 2005). The Weather Guide for the Canadian Forest Fire Danger Rating System (CFFDRS) is intended for operational wildland fire management personnel and forest fire weather practitioners. In the CFFDRS, weather-dependent components are computed for effective use of the CFFWI System and the Canadian Forest Fire Behavior Prediction (CFFBP) System (Lawson and Armitage 2008). See also section III.4.4.(I). Forest managers are interested in estimates of the number of fires likely to occur in a given region during a given time period. This will help them to allocate resources in a better way. Durao et al. (2008) proposed a model to assess fire risk in forestry for Portugal. It is based on conditional probability of fire, I(x), as given by the class of Daily Severity Rating (DSR) for that specified period of time.

The Forestry Tasmania burning risk assessment system (Marsden-Smedley and Chuter 1999) was designed for use in both low and high intensity prescribed burning (post-harvest regeneration burning) in eucalypt forest. Since this model does not cover all the factors required to be assessed for ecological burning, Slijepcevic et al. (2007) developed a tool to cover a broader range of factors and also differentiated between planning and operational phases of prescribed burning. The tool aims to improve the planning and conduct of prescribed burns. This tool uses the concepts outlined in the Australian Standard for Risk Management, a Standard applicable to a wide range of industries and situations. This standard provides a framework for establishing the risk management context and methods of analysis, evaluation, treatment, monitoring and communication of risk. A scalable system for wildland fire risk assessment based upon a repeatable process was developed by Smith (2003) and the approach was implemented in the Florida Wildland Fire Risk Assessment System (FRAS) (http://flame.fl-dof.com/risk/), and selected for the Southern Wildfire Risk Assessment (SWRA) project. See for the latter http://www.dfr.state.nc.us/fire_control/swra.htm.

Insurance companies have long offered forestry cover, more easily calculated than carbon insurance because it is based on the value of wood, for instance as a building material, rather than the value of trees left to grow (Allianz 2008). Burning forests to clear land for farming releases about a fifth of all the greenhouse gases. Paying landowners to let forests grow is promoted by the United Nations as a viable way to fight global warming, but experts first have to puzzle out how to insure trees. The UN's focus so far is on protecting tropical forests.

But owners of forests from Siberia to Scandinavia are interested in carbon credits. Under UN plans, owners will get carbon credits to slow the destruction of tropical forests. But fires caused by lightning, along with other hazards such as storms, insects and illegal logging, are a big risk for insurers and investors. One difficulty is that protecting a forest in one area of the Amazon or the Congo can lead to more logging or burning of forests to clear farmland elsewhere (Doyle 2008).

The only reforestation project approved so far under an existing UN scheme is in the Pearl River basin of south China. That project does not include insurance, because southern China is wet (Doyle 2008). But global warming may affect forests and increase the likelihood of fires. IPCC (2007) projected gradual replacement of tropical forest by savannah in eastern Amazonia by 2050. As the climate changes, there is a greater risk of forest fires, due to hotter temperatures (Box III.4.24).

References

Allianz (2008) Trees to fight warming? Insurers ponder risks. http://knowledge.allianz.com/en/news/viewdetail/trees_insurance.print.html

Doyle A (2008) Trees to fight warming? Insurers ponder risks. http://www.reuters.com/article/environmentNews/idUSTRE4AQ0HY20081127?sp=true

Durao RM, Soares A, Pereira JMC, Real JAC, Coelho MFES (2008) Bayesian classification of a meteorological risk index for forest fires: DSR. In: Soares A, Maria JP, Dimitrakopoulos R (eds) geoENV VI. Geostatistics for environmental applications. Springer, New York, pp 283–294

FAO (2005) Insurance of crops in developing countries. Brochure compiled by RAJ Roberts. FAO Agricultural Services Bulletins, Rome, 94pp. http://www.earthprint.com/productfocus.php?id=FAO106303

IPCC (2007) Fourth assessment report. UN, New York. www.ipcc.ch

Keenan T, Mills G, O'Loughlin K (2005) Summary of WWRP fire weather workshop. www.bom.gov.au/bmrc/wefor/projects/fire_wx_workshop_jun_05/summary_fire_wx_workshop.pdf

Lawson BD, Armitage OB (2008) Weather guide for the Canadian Forest Fire Danger Rating System. Natural Resources Canada, Canadian Forest Service, Northern Forest Centre, Edmonton. http://nofc.cfs.nrcan.gc.ca/bookstore_pdfs/29152.pdf

Marsden-Smedley JB, Chuter D (1999) Fire risk assessment system. Poster Paper Presented at Bushfire ′99, Albury, July 7–9. http://www.csu.edu.au/special/bushfire99/papers/contents.htm

OAA (2008) Environmental risks: the provision of prevention and insurance. Subject 1: Global warming and environmental degradation in Africa: myth? Annual Conference of the Organization of African Insurance, 35th Conference and General Assembly, Algiers, 25–28 May. http://www.african-insurance.org/publications/aio2008/desiree-bayiha-eng.pdf

Slijepcevic A, Tolhurst KG, Sauner G, Whight S, Marsden-Smedley J (2007) A prescribed burning risk assessment tool (BRAT). www.proceedings.com.au/tassiefire/papers_pdf/thurs_aslijpecevic.pdf

Smith JL (2003) A scaleable system for wildland fire risk assessment and fuels management. Proceedings of the 5th Symposium on Fire and Forest Meteorology. Joint Session 5D, Risk Assessment and Decision Support (TRACK IV). http://ams.confex.com/ams/FIRE2003/techprogram/paper_65353.htm

III.5 Applied Agrometeorology of Non-forest Trees

III.5.1 Strategic Use of Climate Information

III.5.1.(a) Combating Disasters by Using Agroforestry

Kees Stigter

Trees outside forests and agroforestry are defined in Box III.5.1. It is recognized (Stolton et al. 2008) that there have been many international agreements and declarations linking the preservation of ecosystem services with the mitigation of disasters. But it must be noted that in many cases it is only the permanent and well-managed setting aside of land and sea as protected areas which can provide the stability and protection so often called for. Protected areas can play three direct roles in preventing or mitigating disasters arising out of natural hazards (Stolton et al. 2008; WWF 2008):

Box III.5.1

Trees grow outside forests in a variety of ways and uses. They cover a wide range of shrub and tree formations with very many species. Applied fields go from agronomy to urban planning, sociology and biology, with practices in agriculture, the environment and livestock production. Studies on "trees outside forests" have come out of numerous domains such as fruit tree cropping, farming systems and apiculture. They are a crucial and core element of agroforestry systems, silvopastoral systems, and urban, rural and community forestry. Trees outside forests are found in most rural landscapes and many agroforestry systems. The International Council for Research in Agroforestry (ICRAF, now World Agroforestry Center) defined agroforestry as a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production, enhancing social, economic and environmental benefits for land users at all levels.

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia;
Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_67,

Much research on the tree/crop/livestock association was produced in almost every developing country and also in some industrialized countries. Despite some of the failures, particularly in large scale actual adoption in developing countries, agroforestry systems were often proposed to promote agricultural development in the tropics. Recent work on the valorization of multipurpose trees and the domestication of trees for products other than wood, have made it easier to measure and promote the potential use of trees in non-forest situations. Even granting that agroforestry is an ancient art, the current interest in trees and their development is unquestionably responsible for some of the newly enhanced awareness of "trees outside forests" (Bellefontaine et al. 2002). See also Box III.4.15 of Sect. III.4.3.(A). A very good introduction to the core aspects of agroforestry was recently given by Cornell and Miller (2007). FAO (2008) lists agroforestry as an agricultural measure in its role in Disaster Risk Reduction.

- Maintaining natural ecosystems, such as coastal mangroves, coral reefs, floodplains and forests that may help buffer against natural hazards.
- Maintaining traditional cultural ecosystems that have an important role in mitigating (the consequences of) extreme weather events, such as agroforestry systems, terraced crop-growing and fruit tree forests in arid lands.
- Providing an opportunity for active or passive restoration of such systems where they have been degraded or lost.

Of the functions listed by Stolton et al. (2008), agroforestry systems come mainly in at the observation that protected areas can provide barriers against the impacts of drought and desertification by:

- Reducing pressure (particularly grazing pressure) on land and thus reducing desert formation.
- Maintaining populations of drought resistant plants to serve as emergency food during drought or for restoration.

As an example, in Portugal different high conservation value landscapes have been maintained due to agrosilvopastoral activities. Most of southern Portugal, for instance, is included in the WWF Mediterranean Ecoregion and is considered a significant biodiversity hotspot particularly due to the presence of evergreen oak savannas, i.e. silvopastoral systems of cork oak and holm oak. Such systems have considerable within habitat and inter-habitat diversity maintained through centuries of human use (Stolton et al. 2008).

Wildfires, particularly those induced by the heat waves of 2003 and 2005, affected Portuguese protected areas mainly through total burned areas. Main cover affected was shrub land, a land use resulting from land abandonment, which points to the socio-economic root of the wildfire problem. Otherwise, the interaction between predicted increasing heat wave frequency through climatic changes and land use changes leading to higher fuel loads on the field will continue to aggravate the fire problem in Portugal (Stolton et al. 2008).

However, also in flood protection, agroforestry is expected to play a role, as shown by implementation of pilot projects along with awareness building activities in the field of agroforestry and energy, in order to protect the watershed above Muminabad town, Tajikistan (Anonymous 2004). In the context of Hurricane Mitch in Central America, smallholder subsistence agriculturalists would be the greatest beneficiary of Vetiver Grass Technology. Damage surveys noted that virtually all the farms using recommended soil and water conservation techniques, especially vetiver grass contour barriers, rock terraces, green mulch and crop residue management, and an indigenous agroforestry system, survived Hurricane Mitch with little damage, while neighboring farms using conventional practices suffered devastating landslides that destroyed homes and degraded fields (Smyle 2000).

The traditional agroforestry system concerned was the Quesungual system, indigenous to the sloping lands in the humid subtropics of southern Honduras: small holder system (<2 ha); natural regeneration (150–500 trees/ha); pruning of trees at 1.5–2 m; residues and weeds slashed and left as mulch; associated with bean, corn, sorghum; use of 65 kg urea/ha with grain crops, beans climb or are hung on pruned trees; fields are not burned to promote regeneration of trees for next year. From farmer's perspective: reduced labor and costs; conserves soil moisture; fuelwood and mulch from tree prunings; trees provide support to bean crop and for harvested corn.

References

Anonymous (2004) Natural disaster risk management in Muminabad. Swiss Cooperation Office, Bern. http://www.deza.admin.ch/ressources/resource_en_169148.pdf

Bellefontaine R, Petit S, Pain-Orcet M, Deleporte P, Bertault J-C (2002). Trees outside forests. Towards better awareness. FAO Conservation Guides 35, Rome, 216pp

Cornell J, Miller M (2007) Agroforestry. In: Cutler J (ed) Encyclopedia of earth. Environmental Information Coalition, National Council for Science and the Environment, Cleveland, Washington. http://www.eoearth.org/article/Agroforestry

FAO (2008) FAO's role in disaster risk reduction. FAO, Rome. http://www.fao.org/fileadmin/templates/tc/tce/pdf/faoroledisasterriskreduction.pdf

Smyle J (2000) Disaster mitigation and vulnerability reduction: perspectives on the prospects for Vetiver Grass Technology (VGT). http://www.vetiver.org/LAVN_disaster.htm

Stolton S, Dudley N, Randall J (2008) Natural security. Protected areas and hazard mitigation. Arguments for Protection Series. World Wide Fund for Nature (WWF) and Equilibrium, The Hague, Netherlands. http://assets.panda.org/downloads/natural_security_final.pdf

WWF (2008) Environmental protection vital to reducing natural disaster impact: WWF. A News Item. http://www.panda.org/index.cfm?uNewsID=133981

III.5.1.(b) Selection Processes of (Changes in) Cropping Patterns Using Non-forest Trees

Luigi Mariani, Osvaldo Failla, and Kees Stigter

In the case studies considered here, land suitability for non-forest trees may be seen in two main different perspectives: (i) improvement of traditional farming systems or (ii) improving/selecting conventional cultivation sites. The two approaches are remarkably different.

Referring to Mediterranean countries, in traditional farming systems, non-forest trees, like grapevine (*Vitis vinifera* L.), olive (*Olea europaea* L.), almond (*Prunus dulcis* Miller) trees, pistachio (*Pistacia vera* L.), fig (*Ficus carica* L.) or cactus pear (*Opuntia ficus-indica* L.) were frequently grown at marginal sites. This was due to their abilities, as highly qualitative crops, to use soils with limitations in terms of (i) suitability for arable cropping, (ii) restrictions to rooting depth, (iii) unfavourable structure or texture, (iv) steep slopes and (v) the often related erosion risk. So over the centuries, by afforestation and frequently by land terracing, important hilly and steeply sloped terrain, as well as moderately arid land, were assigned to non-forest trees.

However, arguments for specific potential of land for fruit crops have also to be found in their climatic characteristics, connected to favorable landscape conditions, as well as in proper choice of species and cultivars, generally native to or selected in that region. Nowadays these farming systems generally suffer from the abandoning of land as a consequence of retiring of elderly growers, which are not replaced by a new generation, because it demands hard labor and yields low income. Moreover, an important role in the sustainability of this kind of farming systems is played by the increase of mechanization and by the availability of irrigation water as stabilizing factor for quantity and quality.

For these reasons, suitability and outlook analyses of non-forest trees cultivation in these contexts have to be focused on products strictly related to the traditional Mediterranean foods and beverages, that are the basis of the local cuisine and pastry, universally known as the Mediterranean diet. Furthermore, these evaluative

L. Mariani (✉)
Department of Crop Science, University of Milan, Milan, Italy
e-mail: luigi.mariani@unimi.it

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_68,

assessments should include the value of the landscapes from the esthetic as well as the historical points of view, including the connections with rural buildings and constructions, like dry stone walls. Moreover, for the appraisal of land suitability, a possible linkage with sustainable tourism is essential, because only the consumers' knowledge and understanding of the special character of the producing land, may tempt him to accept, for the local fruit crops, an adequate price to cover the production costs of these hard to handle farming systems.

Suitability and outlook analyses for non-forest tree to improve conventional or select new cultivation sites, need to consider crops facing definite economic and market conditions. For this reason such analyses refer in general to a small number of specific cultivars, well known by the market. Moreover, soil suitability analysis has to be focused on the possible presence of constraining factors, which may limit plant growth by water or nutritional stresses, as well as on planning irrigation and mechanization (Fernandez-Zamudio and De Miguel 2006).

In areas where non-forest tree cultivation is already developed, suitability and outlook analyses should, as diagnostic criteria, make use of "direct measurements from a number of trial sites located or to be established on different types of land within the survey area" (FAO 1976). Fruit crop performances in terms of yield quantity and quality should be correlated to environmental resources, among which agrometeorological factors assume a dominant importance, to define a specific local model for land suitability assessment for the specific fruit crop under cultivation (Vaudour and Shaw 2005).

Agrometeorological details for grapevine (Tonietto and Carbonneau 2004; Failla and Mariani 2005) should include assessment of radiative and thermal resources in relation to tree physiology and tree phenology, water balance indexes based on specific soil conditions and crop requirements (Failla et al. 2004). By this approach several outputs can be achieved to define land suitability features as well as to recommend specific crop management approaches, as follows:

- site and/or cultivar choice according to expected yielding targets (land capability zoning);
- area delimitations according to distinctive yielding and quality potential (land suitability zoning);
- rootstock choice according to soil qualities and soil constraints;
- soil management according to erosion risk, water balance and soil quality;
- irrigation scheduling according to water balances and tree phenology stages;
- fertilizer application according to soil fertility and nutrient balances;
- plant protection by epidemic risk evaluation;
- harvesting time scheduling according to cultivar phenology, environmental resources and "season".

Finally, suitability and outlook analyses for the selection of new cultivation sites can obviously not rely on experimental data collected in these fields. For this reason, empirical assessments based on assumed relationships between land suitability and environmental resources, taking into account, where possible, suitability models defined for similar areas under cultivation, have to be achieved.

To illustrate this, we use the following agrometeorological service case study (Brancadoro et al. 1999). Pantelleria is a volcanic island located 36.80 °N and 12.00 °E in the Central Mediterranean, south west of Sicily. The grapevine variety grown is Zibibbo, used for the production of the classic Moscato wine. With a surface of only 83 km^2, the variability of main climatic variables (solar radiation, temperature, rainfall, wind and relative humidity) is mainly caused by topoclimatic features (the main mountain – Montagna Grande – has a height of 836 m asl).

The effects of this variability on viticulture are pertinent and a specific analysis carried out on 23 vineyards (Brancadoro et al. 1999) has shown that production areas can be subdivided on the basis of grape ripening periods in very early, early, medium and late (Fig. III.5.1). There are related effects on wine production, for example in aromatic features. Figures III.5.2 and III.5.3 show some relevant agroclimatic indices. The map of Fig. III.5.3 was the result of water balance calculations with a monthly time step. Reference crop evapotranspiration was calculated with the Hargreaves and Samani approach (Allen et al. 1998).

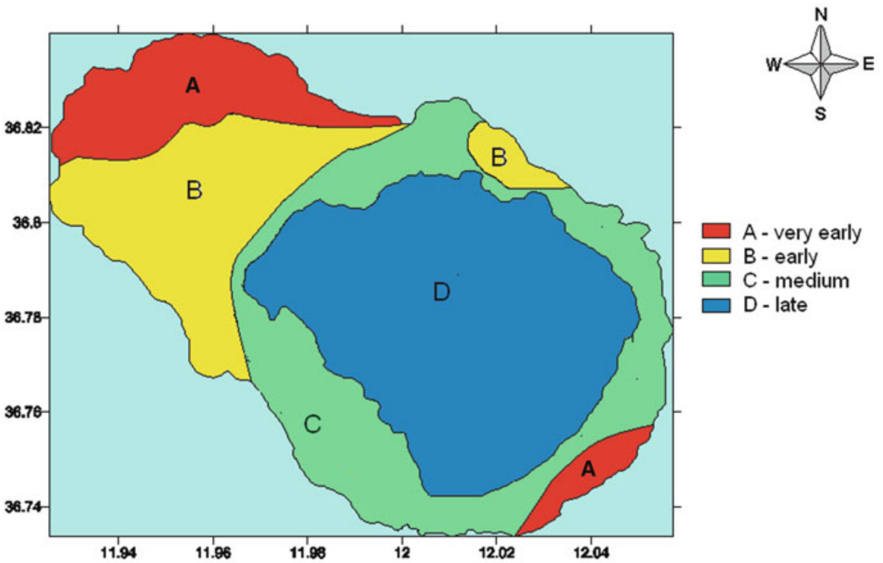


Fig. III.5.1 Pantelleria Island: map of the relative ripening periods of grapes cv. Zibibbo (map produced on the base of the data of Brancadoro et al. 1999)

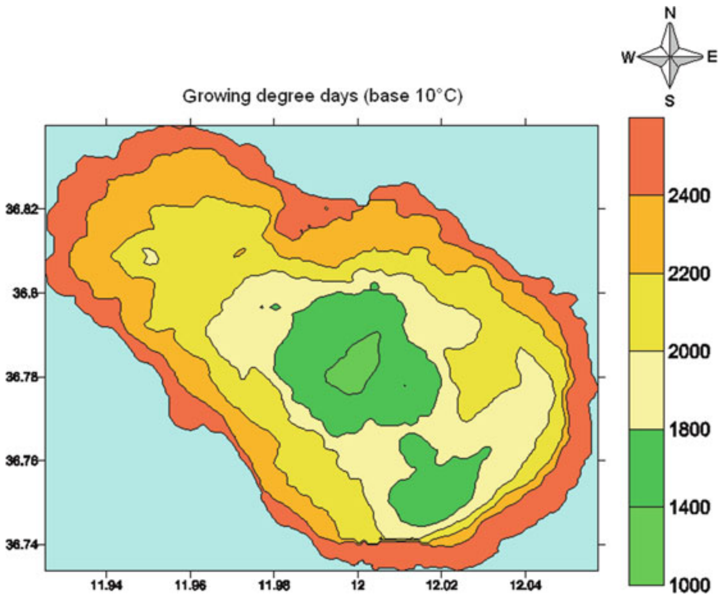


Fig. III.5.2 Map of annual growing degree days above a base value of 10 °C. Air temperatures were spatialized taking into account ancillary information on altitude (a DTM with pixel of 100 × 100 m was adopted). A further improvement of the result could be obtained by evaluating also the effect of exposure

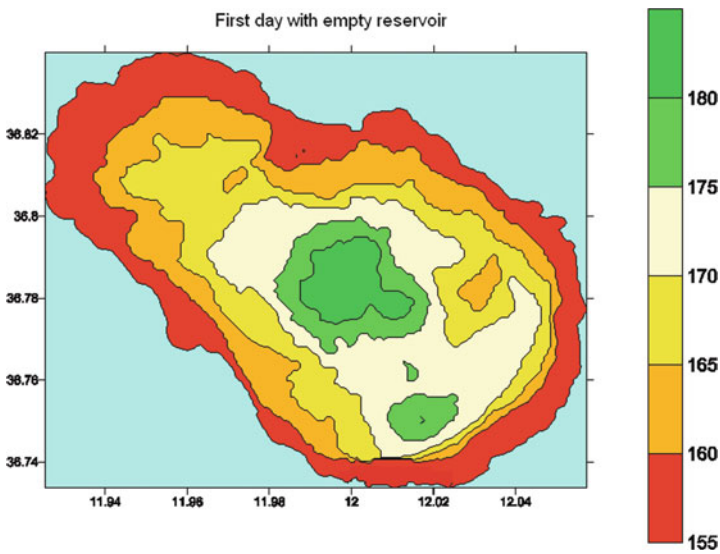


Fig. III.5.3 First day of the year with an "empty soil" for a total Available Water Capacity (AWC) of 100 mm. A significant improvement of the results could be obtained adopting a calculation that also takes into account wind data

Boxes III.5.2 and III.5.3 show some additional issues of related cropping patterns.

Box III.5.2

Training system patterns and canopy management practices have effects on vineyard characteristics: quantity and quality of production, resistance to drought, resistance to biotic and abiotic stresses and so on. Such patterns consider plant architecture and canopy shape as a result of training (by pruning) activities of growers. Grape vine shows two natural growth patterns: liana habit, in fresh and deep soils, but small shrub habit, in dry shallow soils. Traditional training system patterns reflect these two natural habits according to ecological resources. In modern and intensive viticulture, training system patterns are oriented towards full mechanization of vineyard management. For this purpose, canopies are shaped in narrow hedges, composed by a sequence of upward or downward growing shoots, originating from horizontal permanent branches. Canopy management practices refer to six steps after winter pruning and during the vegetative period: suckering, shoot thinning, positioning, hedging and topping, bunch thinning and leaf pulling. Applied agrometeorology provides an essential support for improving vineyard training system patterns and canopy management, both at regional and at farm scale, and with different aims.

Evapotranspiration depends on the LAI trends and on the daily patterns of foliar surface directly exposed to the solar radiation. Modeling the vineyard seasonal course of evapotranspiration, with the aim to match the water demand to the expected natural precipitation and/or irrigation availability, may give an important contribution to sustainable viticulture. Output of the models should include recommendation for the target vineyard LAI and, in hedge shaped vineyards, also for optimal row orientation and row distance as well as canopy height, all factors that affect the crop coefficient Kc (Lebon et al. 2003).

Models for Regulated (water) Deficit Irrigation (RDI) in dry climates proved to be very effective in improving the balance between vegetative growth and crop yield, at the same time reducing water consumption (Wample and Smithyman 2002). RDI practices are based on developing mild water deficit, by reducing or suppressing irrigation during specific phenological phases. The aim is to reduce shoot growth, and, with minor effect on berry growth, to obtain a more suitable ratio between crop load and foliar area, in comparison to no deficit irrigation methods (Fig. III.5.4). Water availability should not limit initial shoot growth; after flowering and fruit setting, shoot growth should cease, to avoid excessive canopy enlargement, possible competition with berry ripening and worsening of grape microclimate. At the same time berry growth should be limited to avoid large crop load. After finishing of shoot growth and onset of grape ripening, plant water status should favour plant photosynthesis and consequently sugar accumulation in berries. At the end of grape ripening, high water deficit is generally suitable for better flavour and phenols accumulation in berries.

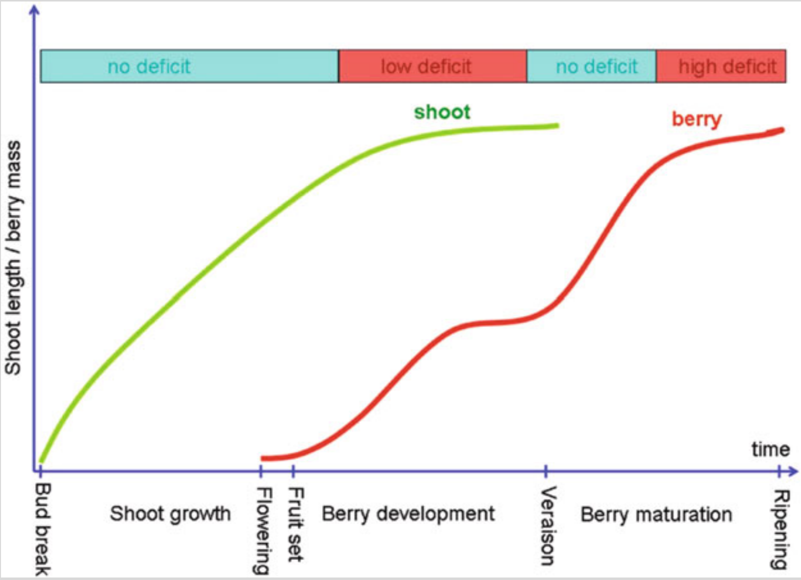


Fig. III.5.4 Idealized curves of shoot and berry growth of grapevine and target plant water status to attain optimal relationships between vegetative and reproductive growth

Vine balance is defined as the proper ratio among vegetative vs. reproductive growth to obtain high quality grapes (Howell 2001). The most suitable leaf area per unit of crop yield should be defined in relation to PAR (Photosynthetically Active Radiation) availability, solar radiation really intercepted by the vineyard canopy, the expected temperature course and possible water stresses (Mariani and Failla 2007; Celette et al. 2008). To quantify the target minimal leaf area per unit of crop load, agrometeorological models should take into consideration grapevine phenology, with special attention to the grape ripening period, as well as the specific grapevine cultivar and the enological objectives (Fig. III.5.5). This kind of semi-mechanistic model could be a support to define the proper ratio among vegetative (leaf area) vs. reproductive growth (crop load) to obtain high quality grapes (Mariani and Failla 2007).

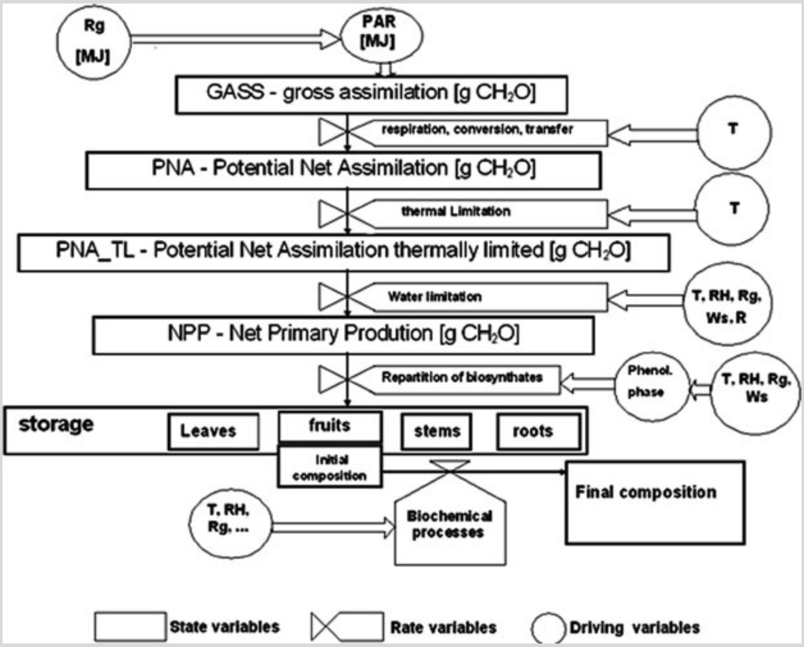


Fig. III.5.5 Scheme of a production model driven by meteorological variables. *Rectangles* are for state variables, *valves* for rate ones and *circles* for driving ones. The role of atmospheric variables that are temperature (T), relative humidity (RH), wind speed (Ws), global solar radiation (Rg) and precipitation (R) is also marked

Grape enological quality is mainly due to fruit secondary metabolism, which leads to the synthesis of polyphenol and aromatic molecules. Like fungal, and in particular *Botrytis cinerea* (grey mould), attacks, these processes are strongly affected by bunch microclimate in terms of temperature, light and humidity. Excessive irradiance to the bunches may lead to sunburn injury in addition to grape withering before ripening. Micrometeorological applications may help to define, according to the local climate and the expected weather conditions, the most suitable canopy management in terms of bunch positioning inside the canopy. The latter depends on its shape and possible leaf pulling around bunches before or during fruit ripening, taking into account the specific grape variety and the required style of wine. A mechanistic approach to the simulation of grape temperature (Fig. III.5.6), based on solving the energy balance related to grape surface, has been recently developed (Cola et al. 2009).

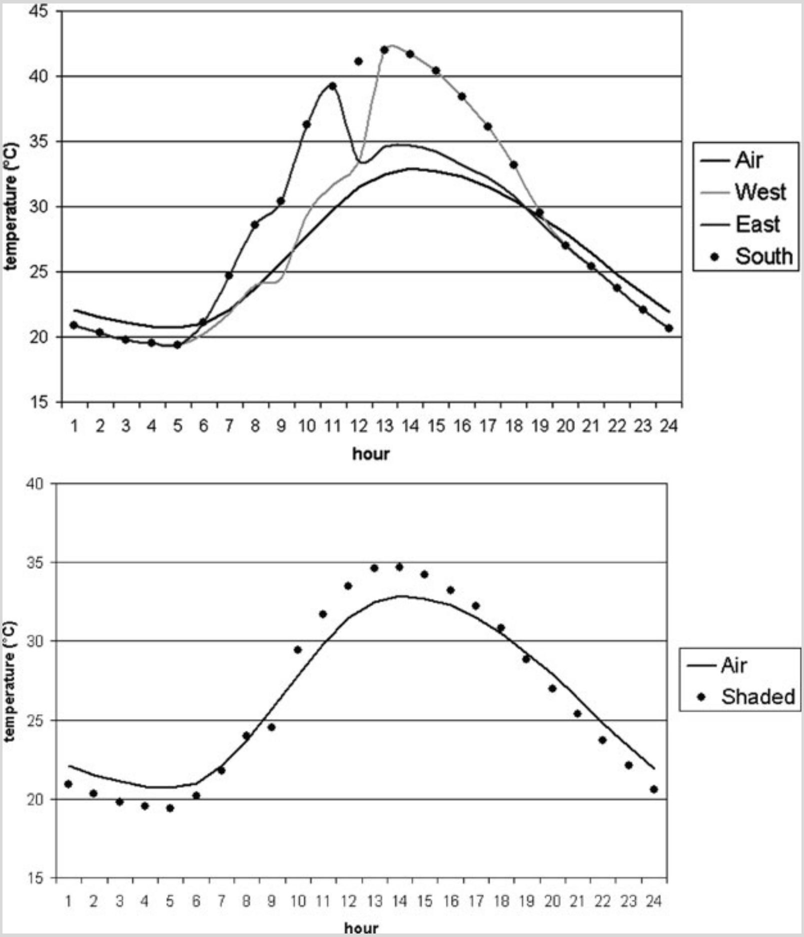


Fig. III.5.6 Simulated temperatures of berries with different exposure based on daily air temperature data (15 August 2003 gauged at Verzuolo – Cuneo province, northern Italy) (Cola et al. 2009); (*top*) sunlit grapes with different exposures; (*below*) grapes inside the canopy

Box III.5.3

A vineyard or orchard cover crop is a noneconomic crop that is grown in vineyard or orchard inter-row spaces and occasionally in rows. Most cover crops in the Mediterranean are classified as winter or summer annuals, which germinate and die in one year or less, or perennials, which live for three or more years (Ingels et al. 1998). The primary positive effect of cover crops in vineyards and orchards is the increase or maintenance of organic matter in the soil profile. This has a lot of effects, such as:

- increase of soil quality expressed as soil biological activity, soil porosity, soil fertility, soil structure, soil water infiltration and available soil water holding capacity;
- increased soil workability (vehicles included), with reduced soil compactness by machinery;
- protection against soil erosion;
- increase in soil organic nitrogen with possible increase in crop growth;
- competition with crops in vigorous sites, helping to reduce unwanted vegetative growth;
- enhanced ecological equilibrium and biodiversity;
- weed suppression.

All these positive effects are in full accordance with guidelines for sustainable farming. On the other hand, cover crops compete for water and nutrients, which drawback must be assessed on a case by case basis.

References

Allen RG, Pereira LS, Raes D, Smith M (1998) Evapotranspiration – guidelines for computing crop water requirements. Irrigation and Drainage Paper 56, FAO, Rome. http://www.fao.org/docrep

Brancadoro L, Pilenga C, Lanati D, Scienza A (1999) La zonazione viticola dell'isola di Pantelleria, Informatore. [Viticultural zoning of the island of Pantelleria], Inform Agrar 16/99:33–34

Celette F, Valdés H, Gary C, García de Cortázar I, Ortega-Farias S, Acevedo C (2008) Evaluation of the STICS model for simulating vineyard water balance under two different water management strategies. Acta Hort (ISHS) 792:155–162

Cola G, Failla O, Mariani L (2009) BerryTone – a simulation model for the daily course of grape berry temperature. Agric For Meteorol, 149:1215–1228

Fernández-Zamudio MA, De Miguel MD (2006) Sustainable management for woody crops in Mediterranean dry-lands. Span J Agric Res 4:111–123

Failla O, Mariani L (2005) Agrometeorological analysis for zoning viticultural aptitude at different scales. http://www.wmo.int/pages/prog/wcp/agm/meetings/bologna05/bologna05.htm

Failla O, Mariani L, Brancadoro L, Minelli R, Scienza A, Murada G, Mancini S (2004) Spatial distribution of solar radiation and its effects on vine phenology and grape ripening in an alpine environment. Am J Enol Vitic 55:128–139

FAO (1976) A frame work for land evaluation. Soil Bull 32, FAO, Rome, 72pp

Howell GS (2001) Sustainable grape productivity and the growth-yield relationship: a review. Am J Enol Vitic 52:165–174

Ingels CA, Bugg RL, McGourty GT, Christensen LP (1998) Cover crops in vineyards: a grower's handbook. University of California Publication 3338, Oakland, 154pp

Lebon E, Dumas V, Pieri P, Schultz HR (2003) Modelling the seasonal dynamics of the soil water balance of vineyards. Funct Plant Biol 30:699–710

Mariani L, Failla O (2007) Meteo-climatic variables as driving variables for agro-forestry ecosystems. Ital J Agron 1(Suppl):9–19

Tonietto J, Carbonneau A (2004) A multicriteria climatic classification system for grape-growing regions worldwide. Agric For Meteorol 124:81–97

Vaudour E, Shaw AB (2005) A worldwide perspective on viticultural zoning. S Afr J Enol Vitic 26:106–115

Wample RL, Smithyman R (2002) Regulated deficit irrigation as a water management strategy in *Vitis vinifera* production. In: Deficit irrigation practices. Water Reports 22, FAO, Rome (Italy), pp 89–100

III.5.1.(c) Selection of Actual Preparedness Strategies for Dealing with Climate, as Adopted in Using Non-forest Trees

H.P. Das

The non-forest trees of this section are rubber, oil palm, cocoa, citrus fruits, grape, coconut and other plantation/orchards trees. Apart from grape and citrus, these tree crops are mainly grown in tropical and sub-tropical areas. Climate is the major determining factor in their geographical distribution. Most of these crops are perennial in nature and require specific climatic conditions for their optimum productions (Rajavel et al. 2005; Chattopadhyay et al. 2005). Box III.5.4 gives an example of preparedness for satisfying water requirements in Italy.

Variations in the weather during the growing season, such as delays in the start of the rainy season, untimely rains or excessive rains, drought etc. would very seriously affect the production. Thus the growth stage of any particular crop at which adverse environmental conditions occur in different years is of significance, as this becomes an important yield determining factor. This is particularly so since susceptibility of crops to the same adverse weather conditions differ from one growth stage to the other and between crop species and even between varieties of the same crop (Sastry 1989).

An important consideration is that there are many difficulties in preparing the land for planting without encouraging erosion. Also, during the later stage of the crop's life, there is a need to maintain sufficient cover to prevent further erosion. Contour terracing for the cultivation of rubber, oil palm and coffee is often practiced on slopes (Doraiswamy et al. 2007). Initially, contour terracing is expensive but is essential on relatively steep land because without it erosion is inevitable during heavy rainfall. The terraces make all operations conducted along the rows, such as weeding, pruning, tapping and collection (in the case of rubber) easier and cheaper (Chan 2001).

H.P. Das (✉)
Retired from Indian Meteorological Department, Pune, India
e-mail: hpd_ag@rediffmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_69,

Box III.5.4 (Contributed by Luigi Mariani and Osvaldo Failla)

In preparedness strategies for dealing with climate, the strategy of water management for commodities like maize or soybean is based on the concept that water requirements must be fully satisfied to maximize production. The same concept cannot be applied to orchards and vineyards, where objectives of quality are dominant and water management is a crucial factor to obtain fruits that meet the requisites of preservation, aroma and taste. Water management in this context means:

- management of irrigation
- storage of precipitation water in soils
- removal of excess water.

In the specific case of the grapevine, the well known resistance to water shortage has often limited the use of irrigation to particularly dry years. In fact, irrigation of vineyards is an agronomic practice only recently adopted with increasing interest for intensification of this crop and the consequent use of expanded and more productive vine training systems than traditional ones. Irrigation, if conducted rationally, stabilizes production in quantity and quality by ensuring availability of water during the most critical stages of cultivation, particularly between the fruit setting and the veraison (onset of ripening). Together with irrigation, fertilizers can be distributed (fertirrigation). However, the excessive use of irrigation may result in a reduction in quality of production, with low sugar contents, delayed ripening, poor color and tight production of grapes. It may also enhance the attack of molds. The quantity of water to be administered is a function of several factors that influence the water balance of the crop and in particular the water retention capacity of soil, climate (temperature, relative humidity, wind, solar radiation and precipitation) and the phenological stage (Fig. III.5.7). Programming of irrigation can be based on water balances (Allen et al. 1998), direct measurement of the moisture content of soil with specific probes or direct measurement of water potential of the plant by means of pressure chambers.

Among the various techniques of irrigation we mention here surface irrigation, sprinkler irrigation and localized drip irrigation (Brouwer et al. 1988). Surface irrigation (Walker 1998) is usually inefficient (only 30–50% of the water is actually used by the crop) and unsuitable for vineyards in hilly areas. Sprinkling systems are more efficient and can be above or below-canopy. In particular the above-canopy system can be used for mitigation purposes during particularly hot years, in order to promote the biosynthesis of coloring elements, but has also negative effects via plant diseases (e.g. downy mildew). Localized irrigation is now interesting the winemakers most, as they can address the need for reduction of water consumption while limiting the

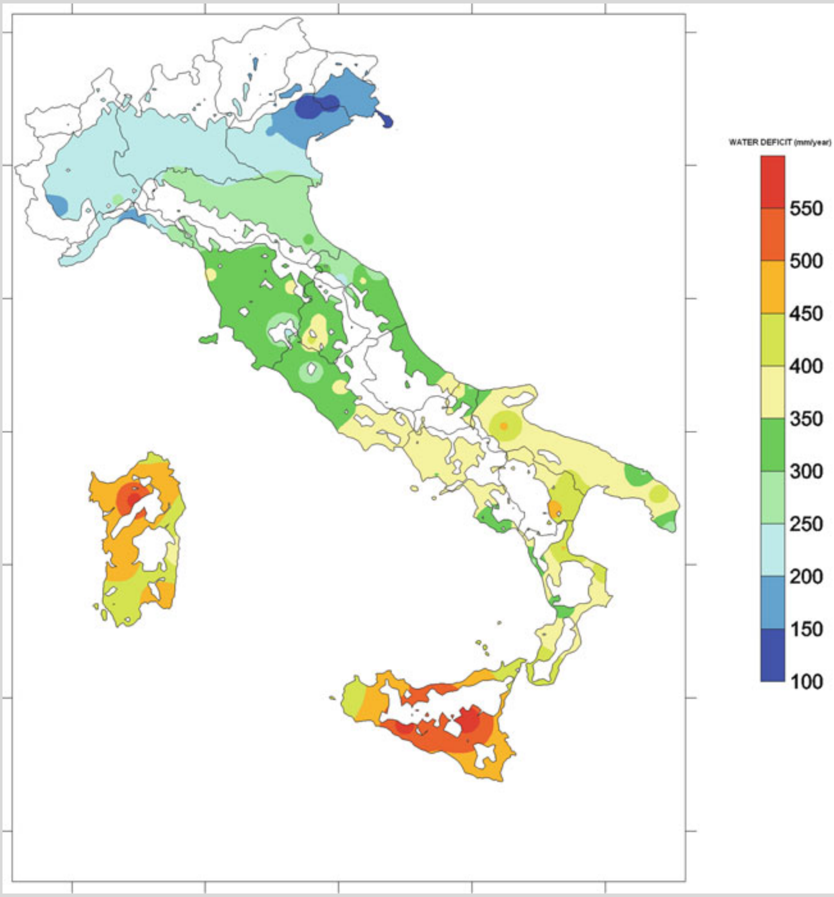


Fig. III.5.7 Mean yearly water deficit that must be cancelled with irrigation of a peach (*Prunus persica* L.) orchard with a grass cover. A territorial water balance model (pixel= 2 × 2 km) is applied to the 1993–2006 period and it is parameterised for a soil with AWC (difference between field capacity and wilting point) of 150 mm in the whole layer of soil explored by roots. Information of areas with altitude above 500 m asl are hidden due to the substantial unsuitability for peach production (source: meteorological data from Cra-CMA weather network, available at www.ucea.it)

negative effects of water excess. A growing interest should be noted in wine growers' climate preparedness strategies for below-canopy localized sprinklers or microjets and the most recent deployment of sub-soil drip irrigation.

To save money, planting is sometimes done on small platforms, 90–120 cm^2, cut out of the slope at appropriate intervals on the contour and each providing a planting place for one tree. These so-called "individual bench terraces" are less effective against erosion than full terracing. On gentler slopes with permeable soil, adequate protection against erosion may be provided by constructing ridges of earth along the contour with a channel on the upper side. Whatever kind of conservation works are conducted, the early establishment of ground cover plants is essential if erosion is to be minimized during adverse weather conditions (Chan 2001).

It has been accepted that cocoa and coffee plants, especially young ones, need some degree of shading for good growth. Various aspects of shade management and manipulation have been discussed by Stigter (1984, 1994) and more recently by Stigter and Abdoellah (2008). It is treated in several parts of this book.

Cocoa and coffee are established either on land occupied by forest or by some other tree crops. In the case of forest, there are two general ways by which cocoa is established, either by planting permanent shade following clear felling, or by thinning the forest before planting cocoa. Clear felling and the planting of shade trees is commonly practiced in the West Indies, South America and Southeast Asia. In certain locations, a number of cocoa diseases can be controlled by simple field sanitation which might involve a change in the level of shade (or improved drainage), though in other cases spraying may be necessary (Owusu-Manu 1996; Chan 2001).

For good grape production it is important that the site has good air and water drainage (see also Box III.5.4). The slope should be gentle enough to allow the easy cultivation and spraying without erosion. The ideal is a level piece of land with sloping land nearby so that cold air can drain off, or a site with a slope of 2–3 f in every 100 f. If the slopes are steeper, the plants should be planted following the contour (Shanmugavelu 1998). Good air drainage is more important with grapes than with other small fruits because, in addition to possible frost damage, infection by fungus such as black rot is more severe where air drainage is poor. Turmanidge (1992) discussed in detail the climatic requirements of the grape crop in Eastern Europe.

Malaysia possesses an “Enviromax” system (Rubber Research Institute of Malaysia 1983) for selecting planting material for rubber. In this system, the rubber growing areas have been divided into “environs” according to factors (e.g. wind damage and fungal diseases) that act as constraints in the selection of clones. Clones are recommended based on the underlying principle of maximizing the yield potential of a particular locality, subject to the inhibitory influence of wind damage, fungal diseases, problematic soils and terracing, and moisture stress (Leong 1991).

The traditional rubber growing tracts of India consist of highly undulating and steep terrain. Therefore the risk of erosion is high and adoption of practices to conserve moisture and soil becomes inevitable in rubber plantations (George et al. 2005). Strong winds may damage rubber trees in various forms. Trees may be uprooted on soils with impeded drainage or where rooting has been limited to the surface layers (Rubber Research Institute of Malaysia 1959). Branch breakages and trunk snaps are also common strong wind damages.

There are three methods commonly used to combat wind damage. The first is to provide shelterbelts for the crop. In China, the shelterbelts are now widely used to protect rubber crops in the more windy areas. The crop is planted in square blocks of 1 ha in highly wind-prone areas and rectangular blocks of 2–3 ha in less windy regions. The second method is to grow trees in higher density, which has been demonstrated to reduce wind losses. In China, rubber stem densities are increased from 375 to 630 trees/ha in order to provide mutual shelter and thicker, less wind-susceptible canopies. The last way is to perform corrective pruning to remove the irregularities of the canopy which render it prone to wind damage. Secondary and lateral branches are removed and the overall tree structure made less top-heavy (Huang and Zheng 1983).

Droughts have immediate effect on plantation trees mostly via the non-recharge of soil moisture, resulting in reductions of streamflow reservoir levels and irrigation potential. Drought management involves soil moisture conservation and plant management, which varies from reducing plant population to fertilization or weed management (Das 2005a). Coconut palms, for example, are exposed to drought of various intensities and durations in their productive features, especially under rain-fed condition.

The results of the study by Rajagopal and Naresh Kumar (2005) in India indicated that impact of drought on coconut yields depends on length and intensity of dry spells. Its coincidence with sensitive phases is also important. Management of drought includes planting drought tolerant cultivars, adoption of drip irrigation and soil moisture conservation practices which should be imposed just after the first spell of monsoon showers. According to Ghosh et al. (2005), life saving irrigation should be provided to the coconut palms in the Indian State of Kerala, when the crop experiences dry spells during the two critical months of July and October.

Citrus, grape and coffee are vulnerable to frost injury and yet they are grown in relatively high-risk freeze areas. The extent of frost injury depends on the intensity and duration of the frost (Adamenko 2003). Frost protection measures can be taken by breaking up the inversion that accompanies intense night time radiation. This may be achieved by heating the air by the use of oil burners, which in turn results in improving the thermal regime of the air layer near the ground and decreases long-wave radiation loss from the soil and the plants. Other methods of frost protection include sprinkling the crops with water, brushing (putting a protective cover of craft paper over plant) and the use of shelterbelts (Das 2004, 2005b). Many of these methods have been mentioned in the examples of agrometeorological services in Part II of this book.

References

Adamenko TI (2003) Hail, high wind and cold injury. In: Agrometeorology related to extreme events. WMO 943, Geneva, pp 107–118

Allen RG, Pereira LS, Raes D, Smith M (1998) Evapotranspiration – guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, FAO, Rome. http://www.fao.org/docrep

Brouwer C, Prins K, Kay M, Heibloem M (1988) Irrigation water management: irrigation methods. Training manual 5, FAO, Rome. http://www.fao.org/docrep
Chan AK (2001) Application of basic knowledge on relationship between meteorological factors and sustainable agricultural production and protection of commercial tree crops. In: Report of the CAgM working groups on weather and climate related to agricultural production. CAgM Report 87, WMO/TD 1079, Geneva, pp 61–80
Chattopadhyay N, Ghosh K, Das HP, Samui RP, Balsubramanian R, Rajavel M (2005) Effect of weather parameters on production of plantation crops in different agroclimatic zones of Kerala. In: Nybe EV, Prasada Rao GSLHV (eds) Drought management in plantation crops. Proceedings of the National Workshop, KAU, Thrissur, pp 88–90
Das HP (2004) Adaptation strategies required to reduce vulnerability in agriculture and forestry to climate change, climate variability and climate extremes. In: Management strategies in agriculture and forestry for mitigation of greenhouse gas emission and adaptation to climate variability and climate change. Technical Note 202, WMO 969, Geneva, pp 41–92
Das HP (2005a) Strategies to combat agricultural drought for sustained agricultural development. In: Nybe EV, Prasada Rao GSLHV (eds) Drought management in plantation crops. Proceedings of the National Workshop, KAU, Thrissur, pp 10–18
Das HP (2005b) Agrometeorological impact assessment of natural disasters and extreme events and agricultural strategies adopted in areas with high risks. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 93–118
Doraiswamy PC, Hunt Jr. ER, Murty VRK (2007) Coping strategies with agrometeorological risks and uncertainties for water erosion, runoff and soil loss. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, Berlin Heidelberg, pp 343–354
George S, Joseph P, Philip A (2005) Mitigating drought in rubber plantation through runoff management techniques. In: Nybe EV, Prasada Rao GSLHV (eds) Drought management in plantation crops. Proceedings of the National Workshop, KAU, Thrissur, pp 28–31
Ghosh K, Chattopadhyay N, Das HP, Samui RP, Balsubramanian R, Rajavel M (2005) Effect of rainfall variability on coconut and tea over Kerala. In: Nybe EV, Prasada Rao GSLHV (eds) Drought management in plantation crops. Proceedings of the National Workshop, KAU, Thrissur, pp 84–87
Huang Z, Zheng X (1983) Rubber cultivation in China. Proceedings of the Rubber Institute of Malaysia Planters Conference, Kuala Lumpur, pp 31–34
Leong YS (1991) Enviromax: an expert system for rubber planting. In: Second National Seminar on Agrometeorology, Petaling Jaya, Malaysia, pp 141–150
Owusu-Manu E (1996) Agroclimatic factors and cocoa production. CAgM Report 67, WMO/TD 747, Geneva, 33pp
Rajagopal V, Naresh Kumar S (2005) Drought management strategies in coconut under different agroclimatic zones. In: Nybe EV, Prasada Rao GSLHV (eds) Drought management in plantation crops. Proceedings of the National Workshop, KAU, Thrissur, pp 35–40
Rajavel M, Balsubramanian R, Chattopadhyay N, Ghosh K, Das HP, Samui RP (2005) Sensitivity analysis of plantation crops productivity in relation to rainfall in India. In: Nybe EV, Prasada Rao GSLHV (eds) Drought management in plantation crops. Proceedings of the National Workshop, KAU, Thrissur, pp 171–176
Rubber Research Institute of Malaysia (1959) Wind damage. Planter Bull Rubber Res Inst Mal 91:147–157
Rubber Research Institute of Malaysia (1983) RRIM planting recommendations 1983–85. Planter Bull Rubber Res Inst Mal 175:355
Sastry PSN (1989) Agroclimatic analysis for semi-arid conditions. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 337–345
Shanmugavelu KG (1998) Establishing the vineyard. In: Shanmugavelu KG (ed) Viticulture in India. Agro Botanica, Bikaner, pp 137–142
Stigter CJ (1984) Traditional use of shade: a method of microclimate manipulation. Arch Geoph Biocl B 34:203–210

Stigter CJ (1994) Management and manipulation of microclimate. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York/Oxford, pp 273–284

Stigter K, Abdoellah S (2008) Cocoa and climate change, can the lame help the blind? Invited Paper Presented at the "2008 Indonesian Cocoa Symposium", Organized by ICCRI, Jember, at Sanur, Bali. An updated version is available at the INSAM website (www.agrometeorology.org) under "Needs for agrometeorological solutions to farming problems" of 3 November

Turmanidge TI (1992) Report on the effect of agrometeorological parameters on viticulture in countries of eastern Europe. CAgM Report 42B, WMO/TD 500, Geneva, 48pp

Walker WR (1998) Guidelines for designing and evaluating surface irrigation systems. FAO Irrigation and Drainage Paper 45, FAO, Rome. http://www.fao.org/docrep

III.5.1.(d) More Efficient Use of Inputs in Cropping Systems Using Trees

Kees Stigter

A representative example of homegardens in Sumatra, Indonesia, is given by Michon and Mary (1990). Families which cannot produce enough rice even for their own needs depend on tree gardens for survival and use them intensively for subsistence as well as monetary needs. Subsistence production is increased through introduction of vegetable crops in clear places under the tree canopy. Moreover, wild vegetables (ferns and small tree species) are intensively favored and regularly collected both for home consumption and for sale in village markets. As to use of inputs, such homegardens have largely a closed forest like ecology (Michon and Mary 1990; see also Box III.5.5). See also Jordan (1985) and Nair (1993) for basics.

Box III.5.5

In the Indonesian homegarden system on Sumatra described by Michon and Mary (1990), management of commercial tree crops is increased, with nutmeg tending to dominate the lower layers as its returns are still greater than those of cinnamon. The association between cinnamon and nutmeg in dense stands is often promoted, while coffee is grown in open places in association with vegetables. Moreover, the forest component itself is intensively used for commercial production: wood production for regional markets is favoured through both silviculture and careful management of spontaneous forest species. The wood of cinnamon is sold as fuel wood to richer families in the villages, and forest products, including fruits, leaves, tubers, and medicinal plants, are favoured in the gardens and collected for local marketing. These garden plots give monetary returns five times higher that those of a rice field of the same size. Adaptation of gardens to adverse economic conditions does not entail significant transformation or intensive specialization. It should serve

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_70,

as a valuable model for commercial village gardening systems in areas where forest resources are being depleted.

Working on more efficient use of inputs, a basic understanding is needed of the process of root water uptake, combining soil physical and plant physiological perspectives in models of plant behavior. This can be related to the water status in their environment, to determine accurate plot-level soil water balances, evaluate plant adaptation to drought, and analyze below-ground competition in mixed vegetation systems (Fernandez et al. 2000). River catchments (or sub-catchments) are the most appropriate levels at which to plan and implement strategies for effective retention of native (woody) vegetation (Scanlan et al. 1993).

The main weakness in sustainable grassland farming in humid ecosystems is the leaching of soil nutrients below the root zone of most forage species. Nature's solution is a tree-dotted savanna – a system where the deeper roots of trees bring up leached minerals, via leaf and fruit drop. You can redesign pasture farms to copy such natural systems (North 2008). But what proportion of trees to crops/grass do we need and how best do we arrange and manage them in actual agroforestry systems are recurrent questions (e.g. Ong and Huxley 1996; North 2008). Early answers to such questions with agrometeorological as well as economical components were give in Ong and Huxley (e.g. Ranganathan and De Wit 1996; Van Noordwijk 1996).

Our understanding of the impact of individual root and root system properties on nutrient capture is limited, so that it is easier to list root system parameters than to specify the functional and ecological significance of these parameters (Atkinson 2000). Nutrient acquisition by roots from soil is a complex process which is dependent on several root features: (i) morphological root characteristics, including mycorrhizal associations, which determine the extent of the interface between plant and soil; (ii) ability to modify the nutrient availability in the rhizosphere; (iii) ability for nutrient uptake through the plasma membranes (Engels et al. 2000). An introduction to the general patterns of nutrient cycling in an agroforestry system in comparison with an agricultural system and a forestry system (see for basics also Jordan 1985) is given in Nair (1993).

In all cases the paths of gains, losses and internal turnovers or tranfers are similar. Inputs come through fertilizer, rain, dust, organic materials from outside the system, and nitrogen fixation as well as weathering of rocks (for other elements); the principal outputs are derived from erosion, percolation (leaching), and crop harvest (for all nutrients), denitrification and volatilization (for N), and burning (for N and S) (Nair 1993). Use efficiencies can only be understood if all these factors are taken into account.

There are ample examples available that the major difference between agroforestry and other land use systems lies in the transfer or turn-over of nutrients within the system or between its components to facilitate increased rates of turn-over without affecting the overall productivity of the system (Nair 1993). There is high potential for soil fertility improvement via more efficient cycling of nutrients and it is often recommended to include nitrogen fixing trees and shrubs in such technologies (Nair 1989, 1993). See also Box III.5.6. It appears that there are several management options for exploiting the advantages of efficient nutrient cycling in agroforestry systems. Specific examples, such as in plantation crop combinations and alley cropping may be found already in the early literature (e.g. Nair 1993).

Box III.5.6

The following can be found in Nair (1993). Agroforestry systems provide an opportunity for modifying nutrient cycling through management which results in more efficient use of soil nutrients, whether added externally (such as fertilizers) or made available through natural processes (e.g. weathering), when compared to agricultural systems. The underlying mechanisms that contribute to efficient nutrient cycling, as well as other nutrient cycling considerations in agroforestry systems, are summarized below:

- There is potential for enhanced uptake of nutrients from deeper soil horizons (where they might be available as a result of rock weathering or percolation past herbaceous plant roots). The deep root systems of trees may reach these sites, which are not often attained by roots or common agricultural crops. This is a significant factor of soil fertility improvement in agroforestry systems.
- Gains from symbiotic nitrogen fixation by trees can be enhanced through tree species selection and admixture. However, it is important to distinguish between nitrogen fixation, an input into the plant/soil system, and nitrogen addition through litter or prunings, which may result in an internal transfer within the system. Much of the nitrogen in the litter is taken up from the soil, originating either from stored reserves in the soil or from added fertilizers.
- Nutrient release from tree biomass can be synchronized with crop requirements by regulating the quality, quantity, timing and method of application of tree prunings as manure or mulch, especially in alley cropping. Different shrubs used in alley-cropping systems vary in the quantity, quality, and decomposition dynamics of leaf biomass. The timing of hedge pruning in alley cropping (and therefore, application of leaf biomass as a source of manure to the planted crop) can be regulated in such a way that the nutrient (especially N) release through decomposition of biomass is synchronized with the peak period of the crop's nutrient demand.
- Management practices that lead to improved organic matter status of the soil will lead inevitably to improved nutrient cycling and better soil productivity. Although the recognized principal benefit from tree biomass in agroforestry systems is nutrient related, there are other advantages

stemming from organic matter addition to the soil that improve crop and soil productivity.

- Another major management consideration in agroforestry is the possibility of reducing nutrient loss through soil conservation and related management strategies.

A good introduction to the relation between root systems of woody plants and availability of nutrients and water is given by Breman and Kessler (1995). The following statements are most relevant to our subject. Roots generally proliferate into soil layers offering the greatest moisture and nutrient supply (if also well aerated). Nutrients are transported with the water, so that the influences of the two factors are difficult to distinguish. In temperate climates roots are more shallow on sandy soils and plants have a higher root to shoot ration than on fine (clay) soils. In semi-arid regions the opposite pattern seems to prevail. Most observations of deep roots are from sandy soils. Tree root penetration into deep soil is related to variation in depth of soil moisture as a result of variation in ploughing and soil texture (Breman and Kessler 1995). Roots may need assistance (Box III.5.7).

Box III.5.7

Using the principles of agroforestry, shrubs and trees can be added to protect and stabilize man-made erosion control structures. However, in cases where soils are not deep and slopes rather steep, experiences from natural forests show that tall-growing trees can be a hazard, and are frequently the cause of landslides during the rainy season. Local farmers on Sulawesi, Indonesia, recognize the danger and, therefore, plant only shrubs on such slopes and frequently prune and lop the woody species which tend to grow tall (Rahayu and Thijssen 2002).

Even in rocky places there are still some plants and trees that grow. This has been a challenge to communities in Flores, Indonesia. If plants can grow in the wild in places where there are only rocks, then why can plants not grow in their hard soils? Pits of $30 \times 30 \times 30$ cm have now been chiseled out and filled up with soil from other places mixed with organic material. Vegetables and fruit trees have been planted in this pit planting system. The first results are promising and the hope is that by bringing back some life to this hard soil, the soil will eventually become healthy (Rahayu and Thijssen 2002). See also Stigter et al. (2005b). There is a proverb in Rajasthan, India, saying “he who applies manure along with water can make even rocky soil yield richly” (Randhawa et al. 1968).

In the same way that Breman and Kessler (1995) compare millet root behavior in Senegal with roots of pine and fruit trees in the USA and Australia, we want to recall from our research in Nigeria that cowpea produced greater root densities and achieved deeper rooting when intercropped with millet and/or sorghum than sole, suggesting adaptation and competitive ability under intercropping. Rooting depths of crops were shallower in a relatively wet season than when water was limiting. Root densities and proliferation of the cereals below the surface layer were much higher in low fertility soils than when nutrients were readily available (e.g. Stigter et al. 2005a). See also Box III.3.1 in Sect. III.3.1.(a).

Under stress, the plants proportionally increased investment in the root system in order to obtain sufficient resources for shoot development, comparable to stories for wooden plants (Breman and Kessler 1995). This is useful knowledge for designing such systems as agrometeorological services (Stigter et al. 2005a). Stress may be caused by drought, mineral deficiencies, pruning, or defoliation of the woody plant, but also by competition with herbs or crops.

References

Atkinson A (2000) Root characteristics: why and what to measure. In: Smit AL, Bengough AG, Engels C, Van Noordwijk M, Pellerin S, Van de Geijn SC (eds) Root methods. A handbook. Springer, Berlin, etc, pp 1–32

Breman H, Kessler J-J (1995) Woody plants in agro-ecosytems of semi-arid regions (with an emphasis on the Sahelian countries). Springer, Berlin, etc, 340pp

Engels C, Neumann G, Gahoonia TS, George E, Schenk M (2000) Assessing the ability of roots for nutrient acquisition. In: Smit AL, Bengough AG, Engels C, Van Noordwijk M, Pellerin S, Van de Geijn SC (eds) Root methods. A handbook. Springer, Berlin, etc, pp 403–459.

Fernandez JE, Clothier BEW, Van Noordwijk M (2000) Water uptake. In: Smit AL, Bengough AG, Engels C, Van Noordwijk M, Pellerin S, Van de Geijn SC (eds) Root methods. A handbook. Springer, Berlin, etc, pp 461–507.

Jordan CF (1985) Nutrient cycling in tropical forest ecosystems. Principles and their application in management and conservation. Wiley, Chichester, etc, 190pp

Michon G, Mary F (1990) Transforming traditional home gardens. And related systems in West Java (Bogor) and West Sumatra (Maninjau). In: Landauer K, Brazil M (eds) Tropical home gardens. United Nations University Press, Tokyo, 257pp

Nair PKR (1989) Agroforestry systems in the tropics. Kluwer, Dordrecht, etc, 664pp

Nair PKR (1993) An introduction to agroforestry. Kluwer, Dordrecht, etc, 499pp

North K (2008) Optimising nutrient cycles with trees in pasture fields. Low Ext Input Sust Agric (LEISA) Mag 24(2):22–23

Ong CK, Huxley P (eds) (1996) Tree-crop interactions. A physiological approach. CAB International, Wallingford, 386pp

Rahayu AD, Thijssen R (2002) Wise lessons from mother nature. Low Ext Input Sust Agric (LEISA) Mag 18(3):22–23

Randhawa MS, Nath V, Vaidya S, Patel HM, Patel MD, Kadam BS (1968) Farmers of India. Vol. IV: Madhya Pradesh, Rajasthan, Gujarat, Maharashtra. ICAR, New Delhi, 318pp

Ranganathan R, De Wit CT (1996) Mixed cropping of annuals and woody perennials: an analytical approach to productivity and management. In: Ong CK, Huxley P (eds) Tree-crop interactions. A physiological approach. CAB International, Wallingford, pp 25–49

Scanlan JC, Prinsley R, Pigott JP, Wakefield S, Van der Sommen F, Dundan F, Stadler T, McLellan R, Farago A (1993) Retention of native woody vegetation on farms in Australia: management considerations, planning guidelines and information gaps. In: Prinsley RT (ed) Allnutt J (comp) The role of trees in sustainable agriculture. Kluwer, Dordrecht, etc, 186pp

Stigter K (CJ), Kinama J, Zhang Yingcui, Oluwasemire T (KO), Zheng Dawei, Al-Amin NKN, Abdalla AT (2005a) Agrometeorological services and information for decision-making: some examples from Africa and China. J Agric Meteorol (Japan) 60:327–330
Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005b) Using traditional methods and indigenous technologies for coping with climate variability. Clim Change 70:255–271
Van Noordwijk M (1996) Mulch and shade model for optimum alley-cropping design depending on soil fertility. In: Ong CK, Huxley P (eds) Tree-crop interactions. A physiological approach. CAB International, Wallingford, pp 51–72

III.5.1.(e) Selection of (Changes in) Management Patterns in Agroforestry

Luigi Mariani, Osvaldo Failla, and Kees Stigter

It should be noted that we have left the livestock component out here because it has been dealt with in Sect. III.3.1.(e) and Chap. III.6.(A). Since we have handled quite some general aspects of this new subject in other sections, we deal here with a case study on the importance of a correct management of interrows of orchards and vineyards, such as with cover crops to prevent soil erosion and to improve the soil by adding organic matter. The relevance of positive and negative effects of cover crops is obviously determined by the crops adopted (species and varieties) but can be strongly modulated by the choices of sowing methods (type and time) and management practices. All these choices must as usual be based on the analysis of:

- physical, chemical and biological characters of the soil;
- climatic resources (solar radiation, thermal and water resources);
- climatic or climate related limitations (drought, water excess, high and low temperatures, strong winds, soil erosion risk, etc.);

Furthermore cover crops:

- must be compatible with the biological cycle and agricultural management of the crop with which they will be grown;
- must show a quick growth and must be able to cover the ground within the time required;
- should not present allelopathic effects;
- should not host diseases or pests.

The most common and economic technique of cover cropping in the Mediterranean involves the management of native species. However, it has the disadvantages of providing slow soil coverage and being very competitive for water. The best way to reduce competition is to use selected grasses or leguminous crops. Pardini et al. (2002) presented a list of grasses (genera *Agrostis, Avena, Bromus, Dactylis, Festuca, Hordeum, Lolium, Poa, Secale* and *Sorghum*) and leguminous crops (*Lotus,*

L. Mariani (✉)
Department of Crop Science, University of Milan, Milan, Italy
e-mail: luigi.mariani@unimi.it

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_71,

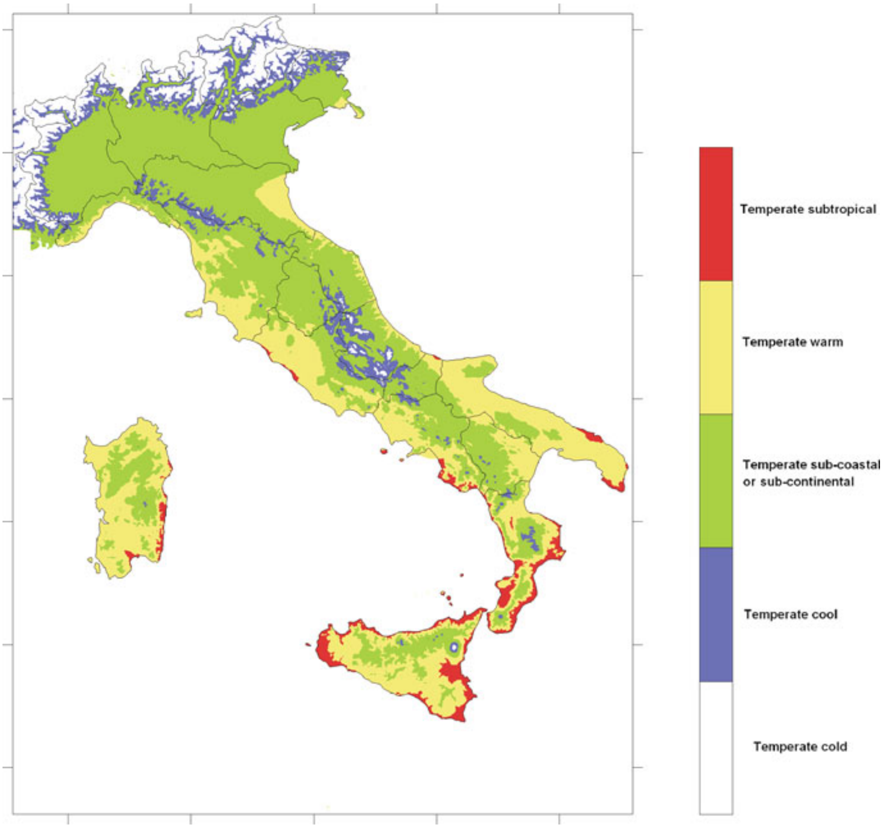


Fig. III.5.8 Climatic classification of Italy according to Pinna (1972) based on mean annual temperature. See the text for cover crops suitable for different climatic areas

Medicago, Melilotus, Pisum, Trifolium, Vicia) adopted as cover crops for vineyards in different parts of the world.

Figure III.5.8 shows a climatic classification of Italy according to Pinna (1972), based on mean annual temperature. Coastal areas show a temperate subtropical climate or temperate warm, while in inland areas there is a gradual transition to the temperate sub-coastal (areas behind the coast), temperate sub-continental (areas of low hills and mountains) and temperate cool (higher mountains) climates. For vineyards in subtropical or warm climates the following cover crops can be adopted (Pardini et al. 2002; Benati and Maggiore 1999): leguminous (*Lotus corniculatus, Medicago polymorpha, Trifolium repens, Trifolium michelianum, Trifolium subterraneum, Trifolium Yannicicum, Vicia sativa*) and grasses (*Bromus catharticus, Bromus inermis, Lolium rigidum*). On the other hand, for vineyards in subcoastal or subcontinental climates, the following cover crops can be considered (Pardini et al. 2002; Benati and Maggiore 1999): leguminous (*Lotus corniculatus, Trifolium* *repens*) or grasses (*Agrostis tenuis, Bromus inermis, Dactylis glomerata, Festuca arundinacea, Festuca ovina, Festuca rubra, Lolium multiflorum, Lolium perenne*). Traditionally interrow management is achieved by mechanical soil tillage, in intensive crop systems and in dry climates, or by a more or less frequent weeding or grass cut, in extensive crop systems and in humid climates (Pardini et al. 2002).

Cover crop management in Mediterranean environments is founded on a principal cut around April–May (Gonzalez Ponce 2007). When there is little rainfall and the non-crop vegetation is large enough to compete with the crop for water and nutrients, the former is removed by mowing, ploughing or through the use of herbicides. Generally speaking, the number of cuts per season varies from two to three. The residual portion is left on the ground where it acts as mulching material.

In general terms, soil along the rows should be left free from weeds by herbicides, mechanical tillage or mulching for a width corresponding roughly to about one third of the planting surfaces, to avoid water and mineral nutrient competition with the crop. This technique will allow to reduce water consumption from soil reserves or from irrigation, and to reduce the fertilizers inputs.

However, cover crops may represent an extra cost for planting management, and the competitive balance between cover and main crop may after all be difficult to maintain. In this domain the role of applied agrometeorology for agrometeorological services could support decision systems aimed at defining the risk of alternative soil management systems to cover crops. Adoption of models or quantitative analyses of water balances, soil erosion and crop production (potential and limited by water and nutrients) will be important in this approach.

References

Benati R, Maggiore T (1999) Scelta, impianto e gestione delle specie da inerbimento. [Choice, planting and management of cover crops] Inform Agrar 38:47–49

Gonzalez Ponce R (2007) Use of cover crops for the control of soil erosion and improving agrosystems. Proceedings of the 5th International Congress of the European Society for Soil Conservation, Palermo, June 25–30, pp 146–147

Pardini A, Faiello C, Longhi F, Mancuso S, Snowball R (2002) Cover crop species and their management in vineyards and olive groves. Adv Hort Sci 16:225–234

Pinna M (1972) La climatologia [Climatology]. UTET, Torino, 462pp

III.5.1.(f) Development of Microclimate Modification Patterns in Agroforestry

Kees Stigter

This literature review is largely an internal one. As follows from many parts of this book, my associates and I have written most abundantly on microclimates in agroforestry. In Part I and in Chap. IV.9 I have discussed the sixteen years (1985–2001) of the Traditional Techniques of Microclimate Improvement (TTMI) Project in Africa. Results are scattered in case studies throughout this book. In Sect. III.2.1.(f) I have discussed and exemplified from China and India the development of microclimate modification patterns in monocropping and related farm practices. In Sect. III.2.2.(ii) the agroforestry came along in this context when Ajit Govind discussed the role of indigenous knowledge. In Sect. III.2.3.(A) I mentioned agroforestry interventions in monocropping for protection purposes and in Sect. III.3.1.(e) I wrote about soil protection by fodder plants in association with fruit trees, and grasses associated with plantation trees. I also wrote there that in even more complex agroforestry, silvopastoral systems are also common. At the same time this shows the variable picture of generation and use that microclimate paterns must show in agroforestry.

In Sect. III.3.1.(f) I talked about the strategic use of (micro)climate information in the adoption of microclimate modification techniques in multiple cropping, while in Box III.3.6 of that same section these microclimate patterns and their consequences are discussed for alley cropping. In Sect. III.3.1.(c) we argue that "adding high density agroforestry will considerably increase the variability that farmers prepare for". Ofori and Kyei-Baffour reason in Sect. III.3.1.(b) that microclimate modification patterns are about the mimicking of natural systems to control the environment to achieve several benefits. They are all connected in one way or the other with multiple cropping and animal husandry to make them effective.

In Box III.3.11 of Sect. III.3.3.(A) I also quoted Robert Chambers in that the general biases in both agricultural and social sciences combine to hide microenvironments from sight, to understate or exclude them in statistics, and to undervalue

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_72,

their importance for livelihoods. That has long applied to microclimates in farming systems as well and is still the main reason for the neglect of designs of improved microclimate management and manipulation as agrometeorological services (see also again Chap. IV.9 and Box III.2.8 of Sect. III.2.1.(f)). That applies to agroforestry systems as well. However, for good designs it must be well understood how microclimate patterns are formed.

The majority of agroforestry systems and practices is presently still found in the tropics and subtropics although they are spreading into other regions. Existing larger areas of agroforestry are certainly not of a homogeneity comparable with non-tropical forests and the distance between trees is generally larger in agroforestry practices. Where that is not the case, the system is of a multi-storey agroforestry nature. This paragraph and the core of what follows is largely based on Stigter (1988, 1994), that I have used here also before as starting points. See also the definition of agrometeorology in Sect. I.2 of this book.

From the micrometeorological point of view, in agroforestry three manipulations or management areas should be distinguished. For the first one regarding radiation, we have the cover effects of shading from solar radiation in daytime and for long wave radiation loss at night. This means that we can manipulate in- or decrease of surface radiation absorption in daytime and surface loss of radiation at night. With a moving sun there are moving shade patterns and east/west or north/south planting is a real issue here. The second manipulation or management area is the flow of heat and/or moisture and cultural measures like tillage and mulching. Influencing speed and direction of air flow are of effect here. Surface modifications (of soil surfaces but also of plant, tree and animal surfaces) influence these flow patterns and so does any modification near these surfaces.

The third manipulation and management area in relation to agroforestry is that of mechanical impact of wind, rain and hail (see for agroforestry also again Baldy and Stigter 1997). Any measure hiding what has to be protected (from wind, rain or hail) should be considered. For that purpose the damaging impact can be (fully or partly) deflected or this impact can be taken (fully or partly) by bodies that are less vulnerable. The flow patterns of wind and water near/on the surface and the consequences of wind, rain/water and hail impact that come into being after the impact sharing and/or deflection must be well unerstood.

These microclimatic patterns and their consequences of radiation behaviour and flows, as carriers of heat, moisture, momentum and whatever is taken/lifted from the surfaces, are studied in microclimatology. For agroforestry its architecture makes these radiation and flow patterns more complicated but the management and manipulation potential much richer. This is confirmed by much material in the other sections of this Chap. III.5.

References

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publication Co., New Delhi; Science Publication Inc., Enfield, 237pp

Stigter CJ (1988) Microclimate management and manipulation in agroforestry. In: Wiersum KF (ed) Viewpoints on agroforestry, 2nd renewed edn. Agricultural University, Wageningen, pp 145–168

Stigter CJ (1994) Management and manipulation of microclimate. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 273–284

III.5.1.(g) Designs of (Changes in) Protection Measures Against Extreme Climate in Agroforestry

Kees Stigter, Luigi Mariani, and Osvaldo Failla

We want to discuss here the protection of non-forest trees against hail and frost. Parts of these stories can be much more generally applied, because protection principles in agroforestry are quite often not system specific.

Hail is a severe disaster with strong effects on quantity and quality of tree and crop production. Hail storms are generated by cumulonimbus clouds and give hail grains ranging from a coffee grain to an orange fruit. When actually such clouds are approaching, then it is useful to find out whether they are indeed likely to produce hail. Radar is useful to sense hail generating power of clouds, and radar performance has increased significantly lately but is not an easy matter (e.g. Wieringa and Holleman 2006).

About the means to strategically fight hail, first of all the cloud seeding of potentially hail producing clouds should be mentioned. Seeding rains out the clouds or diminishes hail stone sizes. Seeding with aeroplanes, rockets and ground-air burners of silver iodide have been tried in the past. Against the attempts to demonstrate the efficacy of this method, it can be argued that the level of noise in natural systems, compared to the magnitude of the signal, has made verification of the reduction of hail with these cloud seeding systems extremely difficult; results of experiments are not conclusive (Garstang et al. 2005). Wieringa and Holleman (2006) summarize their judgement as "Hail suppression is an uncertain meteorological subject in premature agricultural servitude". They also conclude that any operational adoption of the useless "sonic guns" must be avoided and that the sometimes pretended effectivity of explosive rockets and grenades was never proven.

Other means to prevent hail damage are represented by anti-hail nets, placed over the canopy of the trees to reduce the risk of hailstorms injuring the fruits (e.g. TENAX 2009). Several types of netting are now available (e.g. TENAX 2009; Polysack 2009). The micrometeorological effects of hail nets are limited to an about 10–30% decrease in daytime irradiance (Polysack 2009), and the occurrence of mild

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_73,

frost problems (Wieringa and Holleman 2006), while a reduction of less than 1 °C in air temperature within the canopy has also been measured (Kuhrt et al. 2006). Among the reported ecological effects of nets there is also a reduction in the presence of the codling moth (*Cydia pomonella* L.) and in the level of related damage (Tasin et al. 2008).

Frost is another important disaster for crops, including low or wide spaced tree crops, and its effects can for example be prevented by resorting to irrigation or lighting up of trash fires. See also Sect. III.2.4.(I). From a strategical point of view, agroclimatic profiles, including thermal sensitivities of temperate fruit trees, were thoroughly dealt with by Santibanez (1994), while Baradas (1994) dealt equally thoroughly with temperature requirements of various tropical tree crops. One of the big differences between the western world, including Japan, and other parts of the world are the many early quantitative observations made in and around trees and crops, including those related to frost protection.

As early as 1922 threatened orange groves were shown to be protected at windy places, while thoroughly explanatory measurements of night temperatures in a vineyard were made already 75 years ago (Geiger et al. 1995). Blad (1994) discusses the topoclimatic features at hand. Kalma et al. (1992) discuss occurrence, impact and protection of/from frost. In fact the very last pages of Geiger et al. (1995) are fully devoted to protection against low temperatures, with a lot on non-forest tree cases.

It talks most positively about frost covers of special shapes and requirements on vines, man made fogs in vines, and supplying heat in citrus, apple orchards and vineyards. The heat has successfully been applied from irrigation (furrow as well as sprinkler) and a combination of heaters/burners and wind machines. See also the end of Sect. III.2.4.(I) and III.5.1.(c).

The warnings given and the precautions dealt with are strategically still most valuable in agroforestry. For educational purposes, Wieringa and Lomas (2001) deal with frost and frost protection in depth. Most recently we got Snyder and de Melo-Abreu (2005) and Snyder et al. (2005). The goal of these last mentioned two books is to provide to the farming communities a better understanding of freeze protection and to develop strategies to combat crop losses due to freezes (FAO 2009).

References

Baradas MW (1994) Crop requirements – tropical crops. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 189–202

Blad BL (1994) Micro-scale patterns of the climatic elements. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 148–153

FAO (2009) CLIMPAG. Advice and warnings. Frost protection. http://www.fao.org/nr/climpag/aw_4_en.asp

Garstang M, Bruintjes R, Serafin R, Orville H, Boe B, Cotton W, Warburton J (2005) Weather modification, finding common ground. Bull Am Meteorol Soc 86:647–655

Geiger R, Aron RH, Todhunter P (1995) The climate near the ground, 5th edn. Vieweg, Braunschweig/Wiesbaden, 528pp

Kalma JD, Gregory PL, Caprio JM, Hamer PJC (1992) The bioclimatology of frost – its occurrence, impact and protection. Springer, Heidelberg, 312pp
Kuhrt U, Samietz J, Dorn S (2006) Thermal response in adult codling moth. Physiol Entomol 31:80–88
Polysack (2009) Anti-hail nets. http://www.polysack.com
Santibanez F (1994) Crop requirements – temperate crops. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 174–188
Snyder RL, de Melo-Abreu JP (2005) Frost protection: fundamentals, practice, and economics, Vol. 1. Environment and Natural Resources Series 10, FAO, Rome, 223pp
Snyder RL, de Melo-Abreu JP, Matulich S (2005) Frost protection: fundamentals, practice, and economics, Vol. 2. Environment and Natural Resources Series 10, FAO, Rome, 64pp
Tasin M, Demaria D, Ryne C, Cesano A, Galliano A, Anfora G, Ioriatti C, Alma A (2008) Effect of anti-hail nets on *Cydia pomonella* behavior in apple orchards. Entomol Exp Appl 129:32–36
TENAX (2009) TENAX agriculture and floriculture. Anti-hail net. Protection for buds and fruit from all risks. http://www.tenax.net/agriculture/antihail.htm
Wieringa J, Lomas J (2001) Lecture notes for training agricultural meteorological personnel, 2nd edn. WMO 551, Geneva, 196pp
Wieringa J, Holleman I (2006). If cannons can not fight hail, what else? Meteorol Zeitschr 15: 659–669

III.5.2 Coping with Climate Variability and Climate Change

III.5.2.(i) Improving the Issuing, Absorption and Use of Climate Forecast Information In Agroforestrty

Thomas J. Sauer

As we have also already met in previous sections, agroforestry includes a range of practices that combine partial canopies of perennial woody vegetation (trees, shrubs, or hedges) with below-canopy production of forages, arable crops, fruits, berries, and nuts, herbs, or medicinal plants. Agroforestry systems can be broadly grouped into windbreaks and shelterbelts, silvopastoral systems, alley cropping, forest farming, and riparian buffers. Modern agroforestry practices often mimic components of multilayered canopies of natural ecosystems, especially in tropical or subtropical settings.

An agroforestry practice, even within an ecoregion, may include a diversity of species often with the overriding objective of optimizing productivity (food, forage, fiber, or fuel) on an areal basis. The various practices are, of course, adapted for differing climatic conditions and to accommodate economic opportunities and cultural preferences. Nair (1993), Loseby (1995), and Young (1997) provide detailed descriptions of the wide variety of agroforestry systems in use around the globe, including their productive potential and associated environmental benefits. Stigter (1988) described microclimate management and manipulation in agroforestry already in the late eighties.

Establishment of an agroforestry system represents a significant initial investment in capital and physical resources with the economic return and environmental benefits distributed over ensuing years and perhaps decades (Pimentel and Wightman 1999; Veeramani et al. 2003). This makes adoption rates very often low in developing countries (see Box III.5.8). It is now essential to consider potential consequences of climate variability and climate change during the design phase of new agroforestry systems in order to limit potential negative impacts on the growth and productivity of any new plantings (Hansen 2002; Linderholm 2006).

T.J. Sauer (✉)
USDA-ARS, National Soil Tilth Laboratory, Ames, IA, USA
e-mail: tom.sauer@ars.usda.gov

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_74,

Box III.5.8 (Contributed by Kees Stigter)

Adoption of (changes in) agroforestry systems is an important issue because of the low adoption rates often experienced in developing countries (e.g. Kinama et al. 2007). Climate change with increased risks could even decrease such adoption rates. Casey (2004) empirically tested the hypothesis that reducing uncertainty for farmers through investment in human capital increases the likelihood of participation in an agroforestry development program. The primary question is whether or not farmers with more human capital are more likely to be interested in agroforestry. The empirical results lead to the conclusion that investment in human capital, by subsistence farmers in southeastern Mexico, does lead to a higher probability of adoption/investment in agroforestry. Specifically (1) informal specific on-the-job training, (2) formal training, and (3) formal education improve the likelihood of adopting agroforestry. Certainly, Keynes's animal spirits are alive and well in the Yucatan. That is, long-term expectations and investment as a function of those expectations are extremely precarious. It was shown by Casey (2004) for farmers in the Yucatan, as others did for managers in North America, that the likelihood of investment rises when the investor is able to place more "weight" on the profit forecast.

The investment in agroforestry is, at least, partially explained by the confidence farmers have in the available evidence. We should expect future investment in agroforestry will be as precarious as it has been in the past, unless we investigate the farmer's current level of human capital or some other measure to predict his ability to cope with the uncertainties of adopting new production methods. These findings, supported both by the revealed behavior and stated interest, also suggest that low rates of adoption can be improved through the use of public policies affecting access to education, exposure to information about agroforestry from other farmers, and the careful implementation of initial rural development programs. This is an extremely important point. The evidence provided suggests that farmers who have more education, more training, and previous successes are more likely to invest.

Of course, this makes sense, but it also highlights the effect of previous development programs on the implementation of new or current programs. We may have new information pertaining to the benefits of agroforestry, but we may also have to overcome failed efforts in the past in order to implement new strategies. Therefore, working closely with farmers in order to improve their comfort level/confidence with new systems being offered, or analogously, reducing the uncertainty of investing in a new system of production, is an important component of the development process. Agroforestry practitioners can improve the odds of successfully implementing agroforestry by providing continuing education and training to farmers.

Perhaps most important is the role to be played by farmers who have already successfully implemented agroforestry systems. These farmers need to be identified and allowed to participate actively in the dissemination of information and the on-the-job training of new adopters of agroforestry technologies. Agroforestry has been presented as a sustainable alternative to current methods of production in the tropics. If it is to succeed, the accompanying investments in the human capital of farmers through extension programs and on-farm training must be a part of the overall implementation strategy for agroforestry practitioners (Casey 2004).

Some of the same considerations may need to be assessed during the renovation or modification of existing agroforestry systems. In both cases, a combination of features (species, distribution/arrangement, and water and nutrient sources) may be managed to mitigate potential climate change effects. The available options may pursue one of two strategies:

(1) design agroforestry systems for anticipated changes in climate including greater fluctuation of or long-term trends in precipitation and temperature and
(2) design agroforestry systems that are more resilient to climate stresses by including design features or management practices that are more adaptable to the anticipated climate change or extremes.

Climate change predictions involve a complex set of global scale algorithms of biophysical systems based on numerous simplifying assumptions and projected input parameters that are often linked to economic and social factors. Current model predictions for the twenty-first century include continued warming, especially over land and at high northern latitudes, a very likely greater occurrence of hot extremes and heavy precipitation, and likely more intense tropical cyclones with greater peak wind speeds and more heavy precipitation (IPCC 2007).

There is also high confidence in projections that many semi-arid areas will have a decrease in water resources while runoff is expected to increase in some wet tropical areas by 10–40%. Consequences of these climatic changes may be severe as, for instance, by 2020 yields from rain-fed agriculture in some African countries may be reduced by up to 50%. These predictions represent the synthesis of results from numerous climate models each simulating several scenarios based on assumptions of economic growth and population growth, technology development and technology adoption, and climate change mitigation strategies.

Projected climate change scenarios present two types of potential environmental stresses on agroforestry systems. Long-term shifts in temperature and precipitation (total and distribution) may result in "normal" conditions that are outside the nominal range for a particular plant species. These effects may be ameliorated by relatively minor adjustments in management (e.g. planting different crops, draining excess water) although, depending on the degree of change, more radical and expensive adjustments may be necessary (e.g. replacing woody species, supplementary irrigation). The rate of progression of climate change may enable development of effective mitigation strategies and some flexibility in the timing of implementation (Droogers 2004).

The other climate-related environmental stress is with regard to the extremes of episodic events. In this instance, although the agroforestry practice may have adapted to the overall climatic trend, the severity of one isolated event (e.g. cyclone with extreme high winds and heavy precipitation) may produce damage that results in not only failure of annual crops but permanent damage to the perennial species. Recovery from such catastrophic events and the return to pre-event levels of productivity may require significant reinvestment and, depending on the agroforestry system and degree of damage, years or decades for full recovery, including adaptations to better face such events in the future.

Agroforestry practices are innately more resilient to climatic extremes than traditional arable cropping systems in two important ways. First, as was argued also at other places in this book, agroforestry involves multiple species and perennial vegetation, thereby providing greater plant diversity and less vulnerability to climate stress than is provided by monocropping and annual species. Second, the perennial woody vegetation itself serves to modify the local microclimate by influencing airflow and sunlight interception patterns, often protecting the understory species from extremes in temperature and damaging winds (Stigter 1988; Brenner 1996; Cleugh and Hughes 2002).

Deeper rooting by the perennial vegetation also affords greater resilience to drought and increased exploitation of soil water and nutrients from soil layers not readily available to more shallow rooted annual crops. Greater efficiency by agroforestry systems in water use and nutrient cycling is a key strength of these systems and further enhances their potential utility under the uncertainties of climate change (Wallace 1996; Kho 2008).

Although agroforestry practices are inherently more resilient to environmental stresses, sharply increasing global demand for food, fuel, and fiber will translate into intense pressure to produce more of all of these commodities per unit of land area. Climate variation and climate change and the uncertainty surrounding these factors will further reduce the margin of error in designing agroforestry systems for the future.

Large-scale climate forecasts as well as locally-observed trends in temperature and precipitation patterns should be carefully assessed prior to initiation of new agroforestry systems (Hansen 2002). Once established, performance of the system components (survival, growth, and health of perennials, yield of annuals) should be closely monitored and management changes initiated as necessary to compensate for observed environmental stresses introduced by a changing climate.

References

Brenner AJ (1996) Microclimate modifications in agroforestry. In: Ong CK, Huxley P (eds) Tree-crop interactions. CAB International, Wallingford, pp 159–187

Casey JF (2004) Agroforestry adoption in Mexico: using Keynes to better understand farmer decision-making. J Post Keynes Econ 26:505–521

Cleugh HA, Hughes DE (2002) Impact of shelter on crop microclimates; a synthesis of results from wind tunnel and field experiments. Aust J Exp Agric 42:679–701

Droogers P (2004) Adaptation to climate change to enhance food security and preserve environmental quality: example for southern Sri Lanka. Agric Water Manag 66:15–33

Hansen JW (2002) Realizing the potential benefits of climate prediction to agriculture: issues, approaches, challenges. Agric Syst 74:309–330

IPCC (2007) Climate change 2007: synthesis report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri RK, Reisinger A (eds)]. IPCC, Geneva, 104pp

Kho RM (2008) Approaches to tree-environment-crop interactions. In: Batish et al. (eds) Ecological basis of agroforestry. CRC Press, Boca Raton, pp 51–72

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2007) Contour hedgerows and grass strips for erosion and runoff control in semi-arid Kenya. Arid Land Res Manag 21:1–19

Linderholm HW (2006) Growing season changes in the last century. Agric For Meteorol 137:1–14

Loseby M (1995) Agroforestry and its impacts on the environment. European Association of Agricultural Economists (EAAE), Rome, 223pp

Nair PKR (1993) An introduction to agroforestry. Kluwer, Dordrecht, 499pp

Pimentel D, Wightman A (1999) Economic and environmental benefits of agroforestry in food and fuelwood production. In: Buck LE, Lassoie JP, Fernandes ECM (eds) Agroforestry in sustainable agricultural systems. Lewis, Boca Raton, pp 295–317

Stigter CJ (1988) Microclimate management and manipulation in agroforestry. In: Wiersum KF (ed) Viewpoints on agroforestry, 2nd renewed edn. Agricultural University, Wageningen, pp 145–168

Veeramani VN, Maynard LJ, Murugappan C (2003) Economic impact of shelterbelts on groundnut (*Arachis hypogaea* L.) production in therilands: a decomposition analysis. J Soil Water Conserv 58:113–117

Wallace JS (1996) The water balance of mixed tree-crop systems. In: Ong CK, Huxley P (eds) Tree-crop interactions. CAB International, Wallingford, pp 189–233

Young A (1997) Agroforestry for soil management, 2nd edn. CAB International, Wallingford, 320pp

III.5.2.(ii) Sustainable Development and Use of Ecosystems with Non-forest Trees

Thomas J. Sauer

Non-forest trees are components of managed ecosystems including orchards and agroforestry systems (see for example Sect. III.5.2.(i) for a discussion of agroforestry systems) and natural ecosystems such as savannas (Box III.5.9) and riparian corridors (Box III.5.10). Each of these ecosystems includes trees but does not have a complete tree canopy or spatial extent necessary to create a true forest ecosystem. Nonetheless, orchards, agroforestry, savannas, and riparian corridors each represent important land uses in terms of their ecosystem services and in supplying food and fiber for human use.

Box III.5.9

Savannas are grasslands with isolated trees or shrubs and are often found in a vegetative transition zone between forests and grasslands (Dyksterhuis 1957). Savannas can be considered a naturally-occurring silvopastoral system (mentioned in Sect. III.5.3.(A) but dealt with in a wider context in Sub-chapters III.3 and III.4). They are found over a range of climatic zones, from tropical to temperate, and are extensive in the Amazon Basin, Sub-Saharan Africa, India, and northern Australia. Savannas are used predominantly for grazing with the animals foraging not only the grass and forbs but also leaves, branches and pods (from leguminous species) of the trees (Belsky 1994; Ferwerda et al. 2006).

The relative density or dominance of the trees in savannas is influenced by several human-influenced factors including frequency and intensity of fire, harvesting of wood, and grazing management. The distribution of trees is also affected by climate factors as savannas often occupy a climatic tension zone between forests and grasslands. A climate shift to hotter and drier conditions will generally lead to a sparser tree canopy and grassland intrusion,

T.J. Sauer (✉)
USDA-ARS, National Soil Tilth Laboratory, Ames, IA, USA
e-mail: tom.sauer@ars.usda.gov

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_75,

while cooler and wetter conditions tend to favor a fuller tree canopy and forest encroachment on the grassland (Fensham et al. 2009). Precipitation and temperature are also key factors affecting forage productivity and the ability to support grazing animals. Favorable rainfall and temperature patterns will produce more forage and encourage greater stocking density, which may not be sustainable during subsequent sub-optimal growing seasons.

Excessive grazing stock and limited forage production lead to overgrazing and browse damage to trees as the animals struggle to find sufficient food in the short-term. Long-term climate trends may allow for species shifts and adaptations to compensate for the climate change, especially if the changes are gradual. However, abrupt changes or severe variation from year-to-year and the tenuous nature of forage availability/demand pose the real risk of ecosystem collapse. In semiarid regions, persistent drought and increased temperature can lead to loss of plant cover, accelerated soil loss, and desertification, which may be irreversible without large-scale intervention. Sustainable savanna ecosystems can only be achieved when grazing pressure is not excessive, allowing browse and forage species to recover and survive.

Box III.5.10

Natural riparian corridors occur when trees are distributed in a narrow strip along streams, rivers, and some lakes. Although natural riparian forests may be limited in spatial area, they can have a disproportionate impact on ecosystem services, especially with regard to nutrient cycling (Vought et al. 1994; Entry and Emmingham 1996). These forests are located along hydrologic flow paths so that runoff water and shallow groundwater and the nutrients they convey are available for uptake by the trees and understorey vegetation (Lowrance et al. 1984). Much focus on the nutrient cycling processes in riparian forests has been on nitrogen cycling and particularly nitrate removal from shallow groundwater (Groffman et al. 1996; Hill 1996). This ecosystem service has been observed in natural riparian forests and is one of the objectives of planted riparian forests. Riparian plantings are often designed with species and placement to intercept surface runoff, increase infiltration of the runoff, and encourage plant uptake of water from the vadose zone and from groundwater. The primary objective is to slow surface water contribution to the stream and filter out eroded sediment and nutrients to improve stream water quality.

Riparian forests are often highly productive due to the readily available and often nutrient-enriched water in the riparian root zone. Due to their position in the landscape, species of natural riparian ecosystems are generally adaptable to the hydrologic extremes of flood and drought with the ability to tolerate temporary submersion or extend roots to extract water from receding local aquifers. For this reason, riparian forests may be more resilient than some other ecosystems to climatic stress induced by global climate change and variability. Nonetheless, extensive periods of drought or prolonged flooding could result in loss of tree species in the riparian corridor. Decay of the dead wood and litter will return the nutrients and carbon to the soil. This process and the runoff/sediment-trapping features of riparian corridors do create concern that these areas may become excessively nutrient enriched unless some management that includes nutrient removal (i.e. biomass harvesting) is employed.

Orchards include designed plantings of fruit and nut crops and grapes for wine (viticulture) and are typified by intense cultivation practices (see also elsewhere in this Sub-chapter III.5). Many of these species are cultivars that were domesticated and selected for production and quality characteristics sometimes over hundreds or thousands of years. Smith (1953) recognized that well-managed orchards of nut trees, for instance, could provide a perennial supply of concentrated human food calories that was comparable with cultivated annual crops.

The significant investment incurred during orchard establishment often includes provision for managing soil water (irrigation and/or drainage), nutrient additions, and pesticide use to optimize productivity. The high economic value of the commodities produced justifies these investments in infrastructure and inputs. Integrating soil and water management is essential to sustaining or enhancing soil quality, water quality, and food production in orchard ecosystems (Benites et al. 2005).

Due to the intensive management practices of many orchards, there is concern that soil erosion rates, loss of organic matter, and soil contamination is or may become excessive (Montanarelli 2005). This concern is heightened by the fact that orchards are often located on sloping soil, shallow soil, or sandy soil considered poorly suited for arable cropping and are more vulnerable to degradation. Sustainable development of orchard ecosystems needs to include provision for the long term environmental impacts and for an equitable accounting of the ecosystem services of this land use, including esthetic values and cultural values and biodiversity (Baumgartner and Bieri 2006).

Although management practices like irrigation can be adjusted to address climate variability (e.g. increased irrigation to compensate for drought conditions), competition for limited, high quality water resources may create economic restrictions as well as resource restrictions on such coping strategies. Intensification of orchard management has often resulted in degraded soil quality due to compaction, excessive cultivation, and organic matter loss.

Practices that reduce these impacts and restore soil quality will create more drought resistant soils that are also inherently more resilient to climatic extremes (FAO 2005). Less reliance on chemical pest control and more use of mulches or cover crops instead of clean tillage will reduce chemical inputs, reduce evaporation losses, and enhance soil organic matter. Strategies to reduce inputs and/or increase production efficiencies have the potential to improve the economics of orchards and decrease the environmental impacts.

Humans have long used trees to modify their local microclimate, primarily by altering air flow and shading patterns (Oke 1987). Practices that were initially intended to provide greater physical comfort have evolved and expanded into providing multiple and simultaneous benefits or services. Non-forest trees for instance have great potential to increase productivity of a land surface as the trees exploit resources (light, water, and nutrients) that may not be available to non-woody plants (forages and crops).

In combination, the trees and understory plants may have greater potential for production of food, forage, and fiber than either alone, a concept that was termed Land Equivalent Ratio (LER) for intercropping by Mead and Willey (1980) and has been applied to agroforestry systems (Keesman et al. 2007). These aspects have been widely discussed in Sub-chapter III.3 and are also mentioned in some other sections of Sub-chapters III.4 and III.5.

As population expansion puts ever-increasing demands on land for food and fiber production, greater use of non-forest trees offer great potential to increase productivity on a land unit basis by strategic capture of resources not currently utilized by existing land use. In order to sustain this higher level of resource use, careful management must be employed that enhances conservation, recycling, or replacement of water, nutrients, and carbon within the ecosystem.

In managed ecosystems these objectives can be achieved through a variety of practices including composting and mulching with organic residues (leaf litter, crop residues, food processing residuals, and animal manures), which can be used to cover the soil surface and conserve water by reducing evaporation. Recycling of these organic materials will enhance soil organic matter content leading to improved soil quality and resilience. In these ways, integrating trees into production systems increases opportunities to both increase productivity and provide an adaptive strategy for climate extremes (Lin 2007). This has also been dealt with in various other parts of this book.

References

Baumgartner J, Bieri M (2006) Fruit tree ecosystem service provision and enhancement. Ecol Eng 27:118–123

Belsky AJ (1994) Influences of trees of savanna productivity: tests of shade, nutrients, and tree-grass competition. Ecology 75:922–932

Benites J, Pisante M, Stagnari F (2005) The role and importance of integrated soil and water management for orchard development. In: Integrated soil and water management for orchard development – role and importance. FAO Land and Water Bulletin 10, FAO, Rome, pp 21–27. http://www.fao.org/docrep/009/a0007e/a0007e00.htm

Dyksterhuis EJ (1957) The savannah concept and its use. Ecology 38:435–442

Entry JA, Emmingham WH (1996) Nutrient content and extractability in riparian soils supporting forests and grasslands. Appl Soil Ecol 4:119–124

FAO (2005) Drought-resistant soils – optimization of soil moisture for sustainable plant production. FAO Land and Water Bulletin 11, FAO, Rome. http://www.fao.org/docrep/009/a0072e/a0072e00.HTM

Fensham RJ, Fairfax RJ, Ward DP (2009) Drought-induced tree death in savanna. Glob Change Biol 15:380–387

Ferwerda JG, Siderius W, Van Wieren SE, Grant CC, Peel M, Skidmore AK, Prins HHT (2006) Parent material and fire as principle drivers of foliage quality in woody plants. For Ecol Manag 231:178–183

Groffman PM, Howard G, Gold AJ, Nelson WM (1996) Microbial nitrate processing in shallow groundwater in a riparian forest. J Environ Qual 25:1309–1316

Hill AR (1996) Nitrate removal in stream riparian zones. J Environ Qual 25:743–755

Keesman KJ, van der Werf W, van Keulen H (2007) Production ecology of agroforestry systems: a minimal mechanistic model and analytical derivation of the land equivalent ratio. Math Biosci 209:608–623

Lin BB (2007) Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. Agric For Meteorol 144:85–94

Lowrance R, Todd R, Fail Jr. J, Hendrickson Jr. O, Leonard R, Asmussen L (1984) Riparian forests as nutrient filters in agricultural watersheds. BioScience 34:374–377

Mead R, Willey RW (1980) The concept of a "land equivalent ratio" and advantages in yields from intercropping. Exp Agric 16:217–228

Montanarelli L (2005) Emerging issues in soil and water management for vineyard and olive-tree orchards. In: Integrated soil and water management for orchard development – role and importance. FAO Land and Water Bulletin 10, FAO, Rome, pp 3–11. http://www.fao.org/docrep/009/a0007e/a0007e00.htm

Oke TR (1987) Boundary layer climates, 2nd edn. Routledge, London, 435pp

Smith JR (1953) Tree crops – a permanent agriculture. The Devin-Adair Co., New York, 408pp

Vought LB-M, Dahl J, Pedersen CL, Lacoursiere JO (1994) Nutrient retention in riparian ecotones. Ambio 23:342–348

III.5.2.(iii) Detection and Awareness of Increasing Climate Variability and the Elevating Climate Risk in Farming Systems with Non-Forest Trees

H.P. Das and C.J. Stigter

Increasing extreme events have many consequences. For example excessive rain raises the water table which restricts the development of plantation/orchard trees. For shallow rooted rubber crops, if the land is inundated following heavy rainfall, severe damage and even death can occur. However, they may recover well from short periods of shallow inundation. Increase in rainfall also affects the yield of rubber due to loss of tapping days and heavy rainfall may wash the latex out of the cups, resulting in what is known as “washout” (Zhao et al. 2005).

Emphasis on community awareness of and involvement in the mitigation of the effects of increasing climate variability on plantation/orchard crops has recently sharpened, as the priorities are nowadays fixed on the issues associated with educating potential beneficiaries, particularly farmers and plant growers, in the effective use of climate information to reduce impacts from drought and floods and other extreme climate events (Wright 2005). In Australia, for example, mitigation of the effects of flooding is linked to awareness building within the community, and is also effected through specific projects aimed at reducing impacts in problem areas identified in risk assessment studies (COAG 2003). Education programs by government agencies and other organizations provide strategies for minimizing the risks.

For example effective responses to increased frost risk include planting cultivars that are more frost-hardy or which will flower later. If rubber trees experience a radiative or advective type of cold weather, when night temperatures fall sharply to below 5°C, cold damage may occur resulting in withered and discolored leaves, and in severe cases, even the roots may die (Huang and Zheng 1983). The longer the duration of this kind of weather, the more severe the damage will be.

Citrus, grape and coffee are adversely affected by frost. Much of the damage caused to these crops by frost and freezing temperature can be prevented by passive

H.P. Das (✉)
Retired from Indian Meteorologidal Department, Pune, India
e-mail: hpd_ag@rediffmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_76,

as well as active protective measures (Das 2004). For the passive methods, some advance warning can be given using climatological data, while, for active methods, current weather forecasts are required. Frost damage can also be reduced or avoided by the selection of site and appropriate planting material, by using appropriate cultural and management practices and by modifying the physical environment of the crop (Das 2005a).

Compared to forests, agroforestry increases microclimate variability. Agroforestry systems like the cacao cultivation have potentials in combining socio-economic benefits for farmers with environmental advantages. But also here are (micro)climatic risks. In many human-dominated tropical landscapes, agroforestry provides the last forested landscapes, often being more diversified than annual cropping systems or pastures. On the other hand, severe trade-offs may exist between short-term financial incentives of cacao agroforestry intensification and the long-term conservation of ecosystem services (see also Box III.5.11). Production is being intensified, with an increase in input use, and a reduction of shade tree cover, resulting in higher yields at least in the short run. At the same time, cacao farmers are suffering increasing losses due to pests and diseases (STORMA 2008a).

Box III.5.11

The efforts in the improvement of seasonal climate forecasting, including the predictions based on indicators of ENSO (e.g. Nicholls 1985) will definitely increase preparedness and risk management on seasonal to interannual timescale for increasing climate variability (Salinger 2005). This should vastly extend the scope of response farming in the event of any adverse climate fluctuations. Seasonal climate predictions are presented to the users via a number of different media. Prediction services are only useful if they can be understood, applied, and provide value for decision making. In Australia, for example, a huge campaign was mounted during the 1990s to demonstrate to primary producers (farmers, pastoralists, horticulturalists, etc) the links between ENSO and rainfall variations (especially drought). It wanted to advertise the value of seasonal climate predictions in aiding on-farm decision-making and minimizing losses during drought periods.

A greater level of understanding must be established to heighten awareness on the effects of climate variability and extreme climates among the users and about how they should mitigate, prepare for, and recover from the impacts of hazards. An effective media strategy ensures that information aimed at reducing losses from elevating climate risks reaches the users unambiguously (Das 2005b). For example agricultural intensification and ENSO droughts are major drivers of global environmental risk and biodiversity stresses. Little is known how these variabilities affect biodiversity and ecosystem functioning as well as biodiversity/ecosystem service management. Negative effects of local agroforestry management (weeding, fertilization) and the composition of the surrounding landscape (distance to nearest forest) have been reported on insect diversity and ecosystem services such as pollination, herbivory, predation (biological control) and litter decomposition (STORMA 2008b).

References

COAG (2003) Natural disasters in Australia: reforming mitigation, relief and recovery arrangements. Council of Australian Government (COAG), Commonwealth Department of Transport and Regional Services, Canberra, 201pp

Das HP (2004) Adaptation strategies required to reduce vulnerability in agriculture and forestry to climate change, climate variability and climate extremes. In: Management strategies in agriculture and forestry for mitigation of greenhouse gas emission and adaptation to climate variability and climate change. Technical Note 202, WMO 969, Geneva, pp 41–92

Das HP (2005a) Agrometeorological impact assessment of natural disasters and extreme events and agricultural strategies adopted in areas with high risks. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin, etc, pp 93–118

Das HP (2005b) Strategies to combat agricultural drought for sustained agricultural development. In: Nybe EV, Prasada Rao GSLHV (eds) Drought management in plantation crops. Proceedings of the National Workshop, KAU, Thrissur, pp 10–18

Huang Z, Zheng X (1983) Rubber cultivation in China. Proceedings of the Rubber Institute of Malaysia Planters Conference, Kuala Lumpur, pp 31–34

Nicholls N (1985) Towards the prediction of major Australian droughts. Aust Meteorol Mag 33:161–166

Salinger MJ (2005) Climate variability and change: past, present and future – an overview. Clim Change 70:9–29

STORMA (2008a) Ecological and socio-economic assessment of agroforestry management: upscaling from the plot and household level to villages and landscapes. http://www.uni-goettingen.de/en/43726.html

STORMA (2008b) Insect diversity and trophic interactions in relation to agroforestry management and ENSO droughts. http://www.uni-goettingen.de/en/47435.html

Wright WJ (2005) Significance of training, education and communication for awareness of potential hazards in managing natural disaster in Australia. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin, etc, pp 219–239

Zhao Y, Wang C, Wang S, Tibig LV (2005) Impacts of present and future climate variability on agriculture and forestry in the humid and sub-humid tropics. Clim Change 70:73–116

III.5.2.(iv) (Changes in) Adaptation Strategies to Climate Changes with Farming Systems Using Non-Forest Trees

Luigi Mariani and Osvaldo Failla

Historical examples related to wine, as given in the Box III.5.12, show that improvement of genetics (new varieties and rootstocks), agro-techniques (such as pruning, fertilisation, irrigation, weeds and pest management) and enology (techniques able to improve and stabilise the quality of the final products) are essential to counteract future climate variability and change.

One of the main consequences of past climate changes was always changes in the areas for plant cultivation. A very recent example of this is the warm climatic phase following the climatic shift of 1989 in Europe (Werner et al. 2000) and the consequent expansion of European viticulture northwards into sub-continental climates (Koeppen's Cfb), characterised by summer rainfall maximum and enhanced risks of cold outbreaks. There is also expansion of viticulture southwards into the Mediterranean (Koeppen's Csa), where summer drought is the chief limitation, mainly driven by economic and social causes (rapid transition from a low quality viticulture for blending wines to a high quality one). Changes demand adaptations. This leads to new needs in terms of management.

Climatic limitations of Csa and Cfb environments show a relevant interannual variability (Briffa et al. 1994; Jones and Davis 2000; Chuine et al. 2004) driven by synoptic circulations (Beck et al. 2007) that must be managed in order to achieve high quality and more stable levels of production. Within this management of such variabilities, more specifically northern environments need varieties/rootstocks adapted to cool and humid environments and suitable strategies of pest management (for example the problem of *Botrytis cinerea*, grey mould) and southern ones need varieties/rootstocks adapted to drought and suitable strategies of irrigation or dry farming.

L. Mariani (✉)
Department of Crop Science, University of Milan, Milan, Italy
e-mail: luigi.mariani@unimi.it

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_77,

In a more general way, a peculiar spectrum of meteo-climatic resources and limitations will have to be handled for each agricultural system based on non-forest trees (some examples for the main fruit crops of mid latitudes are shown in Table III.5.1). The knowledge of this spectrum is crucial to define:

- tactical options to counteract the variability in the seasonal weather course by means of changes in cultural management (irrigation, summer pruning, pest and weed management, harvest organisation and so on) and/or in post-harvest processes (e.g. wine making, fruit processing industry).
- strategic options to react to climate variability over longer periods based on modification of the whole set of variables of the viticultural and fruit growing model (cultivar, rootstock, planting design, etc.) (Fernandez et al. 1993).

Box III.5.12

Vitis vinifera was probably domesticated 7,000 years ago, as testified by the evidence that resinated wine was being produced on a fairly large scale in the Neolithic period (ca. 5400–5000 BC) at the site of Hajji Firuz Tepe in the northern Zagros Mountains of Iran (Mc Govern et al. 2005). In other words, domestication of grapevine was carried out 3,500 years after the neolithic revolution. The following expansion of viticulture towards Europe (in an area with a climate – Koeppen's Csa and Cfb – quite different from that of the Zagros mountains) the domestication was associated with two fundamental improvements:

- Genetics (with selection of new varieties and possible re-domestication by exchange of genetic material with the ancestor *Vitis vinifera silvestris*, already present in Europe);
- Agro-techniques (for example Columella in "De Re Rustica" [About Rural Matters] of the second century after Christ, described many techniques useful to counteract climate variability).

These improvements where also promoted by the strong climatic variability of the Holocene (e.g.: Mycenaean climatic optimum, cold phase of 800–500 before Christ, Roman climatic optimum, Middle age climatic optimum, Little Ice Age – LIA – and warm phase after the end of the LIA). Quite interesting is the birth of the Champenois wine making method, created in the eighteenth century, in Champagne region, in order to use varieties that were not able to reach normal maturity due to low thermal resources during LIA.

Interesting is also the example of the adoption of rootstocks to counteract the expansion of an aphid (*Philloxera vastatrix* Planchon) imported from North America in the second half of the nineteenth century. Its diffusion in European areas was probably enhanced by the milder climate after the end of the LIA.

Table III.5.1 Some elements of vulnerability for fruit trees at mid latitudes

Non forest trees class	Examples of climatic limitations
Temperate fruit trees (apple, pear, peach, apricot, plum, kiwi fruit, etc.)	– Late frost during budding and flowering phase
	– Early frost (e.g.: important damage for kiwi fruit) – Water availability(for kiwi fruit and in general where high qualitative standards are expected) – Rainy phases mayreduce fruit setting during flowering and enhance the risk of fungal diseases in the vegetative period – Mildness of wintersenhance the risk of insufficient satisfaction of cold needs for species and cultivars with higher needs of chill units
Subtropical fruit trees (orange, lemon, clementine, mandarin and tangerine, etc.)	– Winter frost
	– Water availability(irrigation water is needed for industrial cultivation)
Wine grapes vineyards (large set of varieties of red and white grapes)	Late frostis important only in northern areas due to the late budding of vine. Availability of irrigation water can be a limitation. Rainy periods during vegetative period enhance the risk of fungal diseases
Olive trees (varieties for oil and fruits production)	– Winter extreme frosts thatcan produce the death of plants (critical temperature = $-9\,°C$) – Wateravailability (in the driest environments irrigation is needed for industrial cultivation) – Rainyperiods during vegetative period enhance the risk of fungal diseases

References

Beck C, Jacobeit J, Jones PD (2007) Frequency and within-type variations of large-scale circulation types and their effects on low-frequency climate variability in Central Europe since 1780. Int J Climatol 27:473–491

Briffa KR, Jones PD, Hulme M (1994) Summer moisture variability across Europe, 1892–1991: an analysis based on the Palmer Drought Severity Index. Int J Climatol 14:475–506

Chuine I, Yiou P, Viovy N, Seguin B, Daux V, Le Roy Ladurie E (2004) Grape ripening as a past climate indicator. Nature 432:289

Fernández JE, Moreno F, Martín-Aranda J, Lopez Galvcez J (1993) Water status of olive trees under dry-farming and drip-irrigation. Acta Hort 335:157–164

Jones GV, Davis RE (2000) Climate influences on grapevine phenology, grape composition, and wine production and quality for Bordeaux. Am J Enol Vitic 51:249–261

Mc Govern P, Fleming SJ, Kats SH (eds) (2005) The origins and ancient history of wine. Routledge/Taylor & Francis, London, 362pp

Werner PC, Gerstengarbe FW, Fraedrich K, Oesterle K (2000) Recent climate change in the North Atlantic/European sector. Int J Climatol 20:463–471

III.5.3 Coping with Extreme Meteorological Events

III.5.3.(A) Problems and Solutions in Coping with Extreme Meteorological Events in Agricultural Production, and Challenges Remaining for the Use of Science to Contribute to Problem Analyses and Designing Valuable Solutions in This Context: Non-forest Trees

Kees Stigter

Given that non-forest trees as "trees outside forests" are found in most rural landscapes and many agroforestry systems, we can limit ourselves for this chapter to the latter. We have taken over the definition that agroforestry is a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production, enhancing social, economic and environmental benefits for land users at all levels (Bellefontaine et al. 2002).

We handle here the protective effects (and their problems) against extreme meteorological and climatological events as defined in Sect. III.4.3.(A) for forest (agro) meteorology. There we stated that the most important extreme meteorological events related to forestry, and to agriculture taking place in forest areas (Michon 2005), may be wild fires and bush fires, strong wind systems, long term droughts and floods as well as, to a lesser extent, long heat and cold waves, the latter including frost, snow and icing.

For agroforestry particularly the strong winds and long term droughts as well as long heat and cold waves remain. Fire and floods can be damaging to non-forest trees as well. The fire will, however, not have the extension and threat that it carries in forests for reasons of lower tree densities, lower tree areas and appreciably less fuel material on the soil unless used in combination with mulches. Although trees in agroforestry may suffer from floods, the positive factors are more eye catching such as those from improved tree fallow and bush fallow on erosion control under

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_78,

flowing water (Wilkinson and Elevitch 1998–2004), of hedge row agroforestry on run off and soil loss (Kinama et al. 2007), of riparian zone trees in flood protection (Sebastian 2006) and of drainage/evaporation factors of scattered trees on standing water (Stigter et al. 2003a).

Although new computational fluid dynamics approaches are available (e.g. Wang and Tackle 1997), Wisse and Stigter (2007) note a lack of knowledge in developing regions of the aerodynamic properties of local biological shelter, e.g. as often utilized in African agroforestry (Stigter et al. 2005). The unfortunate reality is that data on wind effects in hot climates are generally sparse (Wisse and Stigter 2007). In De Melo-Abreu et al. (2010), recently wrote the following review.

Humans have long recognized the value of forest plots and woodlands to provide protection of soil, crops and animals from wind effects, either in the lee of relatively closed stands, or, in more open stands, among the trees themselves. In hot arid climates, protective shelterbelts or higher tree densities are often essential if successful intercropping is to be achieved (Onyewotu et al. 2004). In Kenya, tree cover and surrounding hedges prevent mulch from being blown away thereby allowing maize/bean intercrops to be protected from mechanical damage (Stigter et al. 2003b). In Sudan, Mohammed et al. (1996) described the use of an irrigated Eucalyptus shelterbelt of 12 km long and 300–500 m wide for combating wind induced sand invasion into agricultural areas and irrigation canals. However, a much narrower belt of 25 m or so would have done the job. Careful wind observations in contrasting seasons with opposite wind directions showed wind protection from wind reduction details near the sand facing edge (Stigter et al. 2002).

Further work by Al-Amin et al. (2005, 2006) has helped to identify the best species and management requirements needed to control disastrous sand movement in regions prone to desertification. Rainfed shelterbelts of *Eucalyptus camaldulensis* were instrumental in reclaiming desertified land in northern Nigeria, though better planning, possibly using alternative species or scattered trees, would have resulted in greater economic benefits to local millet farmers (Onyewotu et al. 2003a; Stigter et al. 2003b).

Further work by Onyewotu et al. (1998, 2004) found that crop yields may decline significantly if the shelterbelts are established too far apart, or at the incorrect angle relative to prevailing winds. Problems occur particularly when air is very hot, because increased turbulence in the unprotected wake zone (McNaughton 1988) exacerbates soil moisture loss and heat stress on the crops. The conclusion is that shelterbelts in arid regions must be well planned, in consultation with local experts, including farmers/producers, and properly maintained, if maximum benefits to crop production are to be realised.

Kainkwa and Stigter (1994) investigated the wind protection provided by a savannah woodland edge in northern Tanzania, also showing the influence of diminishing tree densities due to tree felling. Considerable initial wind tunneling effects were found due to variations in the distribution of tree biomass, but wind speed was reduced by at least 50% at distances of 110 m or more from the leading edge. The saturation wind speed was the same at 1 and 2.5 m height and remained relatively constant in canopy gaps as large as 50 m, due to the association with wind fields above the trees.

In some cases, studies show that shelterbelts are not necessarily the best solution. For example, Zhao et al. (2006) working in Inner Mongolia, found that planting perennial grasses with shrubs on shallow soils provided better soil protection against wind erosion than difficult to establish tree cover. Stigter et al. (2002), reporting among others on work in Nigeria, suggested that higher densities of scattered trees would be more effective in soil and crop protection in areas of west Africa where parkland agroforestry is traditionally practised. Also Oteng'i et al. (2000) came to conclusions preferring other configurations in Kenya.

Gomes da Silva (2007) wrote that grazing animals or animals giving birth will seek shelter from strong winds, especially during cold weather. Structures or trees can markedly reduce wind speed, and can be beneficial to the survival of exposed animals (especially newborn). But windbreaks have an importance much beyond these benefits, especially in the tropical and subtropical regions. In using trees as windbreaks there is a trade-off between any enhanced growth of the associated grassland and the area occupied by the shelter trees, unless they have associated timber or fuel value (e.g. Onyewotu et al. 2003b).

The use of leguminous trees or shrubs can be a practical means to counteract the effects of the wind and heat stress as well as to improve the animal diet. Implications for livestock can be important regarding changes in weather and climate patterns in rangeland and semi-arid lands. In view of the fact that livestock breeding plays a primary role in the economical structure of many developing regions and the fact that the frequent onset of droughts causes considerable losses of animals due to scarcity of fodder, it is vitally important to supplement pasture amelioration with fodder trees and shrubs in order to minimize such losses (Das 2004). They will not only supply food for animals, but also serve as a shelter from the solar radiation and create a microclimate more favourable for regrowth of grass spoiled by the dry conditions (e.g. Onyewotu et al. 2003a). See also Box III.5.13.

Box III.5.13 (Contributed by E. Ofori and N. Kyei-Baffour)

Livestock production can be made more intensive, profitable and conservation conscious of tree resources and soil resources by relying on more intensive systems, sustained in multifunctional use of the land. Traditional mono-herding has multiple problems. These are overgrazing resulting in serious land degradation, soil erosion due to heavy rain in the wet season and winds in the dry season, soil drying, loss of soil cover, making production unsustainable. The end results are soil erosion, low productivity, fires and loss of biodiversity. It is a cost to the environment, causes reduced land productivity and loss of livelihood. For sustainable herding, multiple species herding combined with agroforestry and pasture or fodder would have several benefits to the farmer, the environment and global food security.

Trees can be planted for multiple purposes, including in pastures, and managed in such a way that land degradation due to overgrazing, soil erosion, reduced biodiversity do not occur. Having a multiple use of the land would generate new products, new services, optimal use of the land and increased income. Multiple species herding, supported by agroforestry or silvopastoral systems, could increase land productivity together with added advantages, and provide a wide range of habitats. Trees can be a source of dry season fodder for the livestock, shade from their leaves may reduce heat stress and increase feed intake. Trees in agricultural landscapes may also contribute to increased levels of biodiversity. Scientific and logistical support of participatory development of improved farming systems as described in the bulk text, including farming systems of mixed crops cum livestock farming where possible, deserves attention. This also demands development of related local veterinary services and nursery services assisted by infrastructure and market developments.

Drought therefore is another factor to be dealt with. Worsening weather events on several continents provoked assistance to countries hit by drought and desertification. Much tree growing was undertaken in this context, also without the wind factor playing a role. Trees with their deeper rooting have a much better survival rate under drier conditions and create conditions in which for example grasses return to desertified areas (Onyewotu et al. 2003b). Sometimes, however, even trees have to be irrigated (Mohammed et al. 1995a). Both these research undertakings in arid areas were also popularized for extension purposes (Onyewotu and Stigter 1995; Onyewotu et al. 2003b; Mohammed et al. 1995b). High temperature stresses are part and parcel from this picture and their basics may be found in De Melo-Abreu et al. (2010).

The same applies to cold stresses and their often related inconveniences of snow and ice. Extreme low temperatures can lead to frost, which can damage trees, especially young trees and saplings or new growth. The wider the distances (the lower the tree density) the more dangerous frost can be. Two different types of frost do exist, depending on the meteorological conditions: advective frost and radiation frost. Advective frosts are associated with cool air currents and damage may be caused especially to young saplings or new growth. However, at most locations radiation frosts are more common and occur on calm clear nights. Radiation frosts can be damaging to plantations during spring and autumn (e.g. Rahimi et al. 2007). Furthermore, in undulating terrain, cooled air can pool as a result of poor air drainage and temperature inversions develop. Under these circumstances, frost hazard may be a significant recurrent problem, which requires particular attention from managers (De Melo-Abreu et al. 2010).

Given the experience with local problem solving (e.g. Stigter et al. 2002; Onyewotu et al. 2003a), remaining challenges are particularly to intensify contacts with farmers in structures like Farmer Field Schools to better assess and understand local needs and farmers' ideas about feasible solutions.

References

Al-Amin NKN, Stigter K (CJ), Elagab MAM, Hussein MB (2005) Combating desert encroachment by guiding people, wind and sand. J Agric Meteorol (Japan) 60:349–352

Al-Amin NKN, Stigter CJ, Mohammed AE (2006) Establishment of trees for sand settlement in a completely desertified environment. Arid Land Res Manag 20:309–327

Bellefontaine R, Petit S, Pain-Orcet M, Deleporte P, Bertault J-C (2002). Trees outside forests. Towards better awareness. FAO Conservation Guides 35, Rome. http://www.fao.org/docrep/005/Y2328E/y2328e00.HTM

Das HP (2004) Adaptation strategies required to reduce vulnerability in agriculture and forestry to climate change, climate variation and climate extremes. In: Management strategies in agriculture and forestry for mitigation of greenhouse gas emissions and adaptation to climate variability and climate change. Technical Note 202, WMO 969, Geneva, pp 41–92

De Melo-Abreu JP, Daldoum MA, Andrews PL, Bastos TX, De Groot WJ, Fleming R, Fleming R, Fujioka F, Goldammer JG, Govind A, Harrison J, Keenan T, Price D, Statheropoulos M, Stigter K, Wain A (2010) Applications of meteorology to forestry and non-forest trees. Chapter 11 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Gomes da Silva R (2007) Guide to agricultural meteorological practices (GAMP), Chapter 11: Weather and climate and animal production (draft by 3rd edn). WMO 134, Geneva, available at the WMO/CAgM and INSAM websites. http://www.agrometeorology.org/fileadmin/insam/repository/gamp_chapt11.pdf

Kainkwa RMR, Stigter CJ (1994) Wind reduction downwind from a savannah woodland edge. Neth J Agric Sci 42:145–157

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2007) Contour hedgerows and grass strips for erosion and runoff control in semi-arid Kenya. Arid Land Res Manag 21:1–19

McNaughton KG (1988) Effects of windbreaks on turbulent transport and microclimate. Agric Ecosyst Environ 22/23:17–36

Michon G (2005) Forest culture. The Overstory, Paper 158, PAR, Holualoa. http://www.mail-archive.com/sustainablelorgbiofuel@sustainablelists.org/msg52658.html

Mohammed AE, Stigter CJ, Adam HS (1995a) Moving sand and its consequences in and near a severely desertified environment and a protective shelterbelt. Arid Soil Res Rehabil 9:423–435.

Mohammed AE, Stigter CJ, Adam HS (1995b) Holding back the desert: a eucalyptus shelterbelt in central Sudan. Agrofor Today 7(1):4–6

Mohammed AE, Stigter CJ, Adam HS (1996) On shelterbelt design for combating sand invasion. Agric Ecosyst Environ 57:81–90

Onyewotu LOZ, Stigter CJ (1995) Eucalyptus – its reputation and its roots: millet and a eucalyptus shelterbelt in northern Nigeria. Agrofor Today 7(1):7–8

Onyewotu LOZ, Stigter CJ, Oladipo EO, Owonubi JJ (1998) Yields of millet (*Pennisetum typhoides*) as a function of multiple shelterbelt protection in semi-arid northern Nigeria, with a traditional and a scientific method of determining sowing date. In: Van Duivenbooden N, Neeteson JJ (eds) Using scientific and indigenous knowledge at different scale levels to develop sustainable agriculture in the Sudano-Sahelian zone of West Africa. Neth J Agric Sci 46: 53–64

Onyewotu LOZ, Stigter CJ, Abdullahi AM, Ariyo JA, Oladipo EO, Owonubi JJ (2003a) Reclamation of desertified farmlands and consequences for its farmers in semiarid northern Nigeria: a case study of Yambawa rehabilitation scheme. Arid Land Res Manag 17:85–101

Onyewotu L, Stigter K, Abdullahi Y, Ariyo J (2003b) Shelterbelts and farmers' needs. LEISA Mag Low Ext Input Sust Agric 19(4):28–29

Onyewotu LOZ, Stigter CJ, Oladipo EO, Owonubi JJ (2004) Air movement and its consequences around a multiple shelterbelt system under advective conditions in semi-arid northern Nigeria. Theor Appl Climatol 79:255–262

Oteng'i SBB, Stigter CJ, Ng'ang'a JK, Mungai DN (2000) Wind protection in a hedged agroforestry system in semi-arid Kenya. Agrofor Syst 50:137–156

Rahimi M, Khalili A, Hajjam S, Kamali GA, Stigter CJ (2007) Risk analysis of first and last frost occurrences in central Alborz region, Iran. Int J Climatol 27:349–356

Sebastian M (2006) Riparian buffer zone restoration for food security. The Overstory, Paper 167, PAR, Holualoa. May be read at http://www.ileia.org/index.php#m_issues (search: overstory)

Stigter CJ, Mohammed EA, Al-Amin NKN, Onyewotu LOZ, Oteng'i SBB, Kainkwa RMR (2002) Agroforestry solutions to some African wind problems. J Wind Eng Indust Aerodyn 90: 1101–1114

Stigter CJ, Das HP, Murthy VRK (2003a) Beyond climate forecasting of flood disasters. Invited Lecture on the Opening Day of the Fifth Regional Training Course on Flood Risk Management (FRM-5) of the Asian Disaster Preparedness Center (Bangkok) and the China Research Center on Flood and Drought Disaster Reduction (Beijing), Beijing, September. Available from ADPC (Bangkok) on CD-ROM. Also available at http://www.agrometeorology.org/fileadmin/insam/repository/ADPC2mp.pdf

Stigter CJ, Al-Amin NKN, Oteng'i SBB, Kainkwa RMR, Onyewotu LOZ (2003b) Scattered trees and wind protection under African conditions. In: Ruck B, Kottmeier C, Mattheck C, Quine C, Wilhelm G (eds) Wind effects on trees. University of Karlsruhe, Germany, pp 73–80

Stigter CJ, Onyewotu LOZ, Al-Amin NKN (2005) Wind and agriculture; an essential subject of the African Participatory Research Agenda. Paper #103. In: Naprstek J, Fischer C (eds) Proceedings of the 4th European & African Conference on Wind Engineering. ITAMAS, Prague, 11pp [Available on CD-ROM. Also in Book of Extended Abstracts, pp 306–307]

Wang H, Tackle ES (1997) Model-simulated influence of shelterbelt shape on wind sheltering efficiency. J Appl Meteorol 36:697–704

Wilkinson K, Elevitch C (1998–2004) Improved fallow. Paper #42. In: Elevitch CR (ed) The overstory book. Cultivating connections with trees, 2nd edn. PAR, Holualoa. http://agroforestry.net/overstory/overstory42.html

Wisse JA, Stigter K (2007) Wind engineering in Africa. J Wind Eng Indust Aerodyn 95:908–927

Zhao Caixia, Zheng Dawei, Stigter CJ, He Wenqing, Tuo Debao, Zhao Peiyi (2006) An index guiding temporal planting policies for wind erosion reduction. Arid Land Res Manag 20: 233–244

III.5.3.(B) Designing and Selecting Efficient Early Warning Strategies and Increasing Their Efficiencies for Agroforestry Farming Systems

Simone Orlandini and Francesca Natali

Monitoring of environmental variables and provision of the derived information (see Box III.5.14) represents necessary support for decision making in agroforestry management and planning (Black et al. 2000). Information can hardly be used as a raw datum, but it needs to be analysed, processed and organised according to its final operational use. New approaches to agriculture seek to increase the application of agrometeorological information for the assessment of environmental risks (Orlandini et al. 2007), also based on the establishment of agrometeorological services (WMO 2010).

Box III.5.14

Agroforestry systems are largely dependent on weather and climate (Reifsnyder and Darnhofer 1987). Management and planning decisions are made under conditions of risk and uncertainty due to the high level of complexity and interactions existing among the system components. To reduce the level of risk, farmers increased the quantity of inputs above the necessary requirements, with the aim of decreasing the variability of agroforestry responses. Unfortunately, the consequence of this strategy is the increasing of environmental impact and production costs without obtaining the expected goal (Travis et al. 1992). A solution to interrupt this negative trend is to substitute expensive and pollutant chemical and energetic inputs with elaborated environmental information of high quality. In this way it is possible to decrease the risk of the uncertainties of decision making and thus to minimise the excess of input application, as well as to increase the potential income (Maracchi 2001).

In these contexts of information and advisory services (also Box III.5.15), early warning systems (EWSs) are essential components of risk and impact prevention

S. Orlandini (✉)
Department of Agronomy and Land Management, University of Florence, Florence, Italy
e-mail: simone.orlandini@unifi.it

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_79,

and management. They deal for example with the analysis of agroforestry system conditions and weather and are generally composed of several elements:

- detection and monitoring of events;
- integration and processing of meteo-climatic data with other relevant information, e.g. vegetation cover, growth and development and values at risk;
- modeling capabilities of extreme event occurrence and behaviour;
- dissemination of information to the end-users: policy-makers, extension services, farmers, insurance companies.

Box III.5.15

The operation of non-forestry agriculture with trees, such as tree nurseries and orchards, is in various respects similar to the production of any other agricultural crop. Some of the principles applicable to intensively cultivated garden crops also apply to production of non-forest trees. Where non-forest trees differ is dealt with in other sections of this chapter. Ong et al. (2000) analyse different aspects such as tree and crop growth, system performance, resource capture, hydrology and microclimate to improve the mechanistic understanding of tree/crop interactions. Ong et al. (2000) support the development and validation of process-based simulation models describing resource capture and tree and crop growth in semi-arid agroforestry systems. There remain, however, difficulties that are largely due to the inhomogeneities of such systems (e.g. Stigter 2009). Forecasts and information of precipitation amounts, intensity and duration allow better management of water resources under circumstances where nurseries require irrigation or drainage installation for optimum development of seedlings or fruits. For example, water stress on trees will affect both the growth and quality of the final product during drought periods and waterlogged ground is potentially destructive to sensitive tree species (De Melo-Abreu et al. 2010). See also Box III.5.4 in Sect. III.5.1.(c).

The role of EWSs is also enhanced by considering the impacts of climate change and variability. The Intergovernmental Panel on Climate Change in its most recent report (IPCC 2007) highlighted the need for more detailed information about regional patterns of climate change, their increasing variability and the different distribution of extreme events (Murdiyarso 2006). Particularly in complex climate zones, it is very important to know which areas could be more affected by climate change and thus more at risk for extreme events (Bartolini et al. 2008). This definitely also applies to regions where agroforestry is important.

EWSs may involve models or indices (e.g. IRIN 2009), included in the set up of the systems, where applicable integrated with other advanced technologies, which rely on remote sensing data, geographic information systems, numerical weather models, evaluation of synoptic weather information and international communication systems (e.g. GEO 2008). Most of these systems were developed for crop observations but other vegetation may often be included. Internet and satellite telephone links may be important channels for information flow (Rosiek and Batlles 2008).

Agroforestry, by its very nature, creates complex systems with impacts ranging from the site or practice level up to the landscape and beyond. Computer-based Decision Support Tools (DSTs) help to integrate information to facilitate the decision making process that directs development, acceptance, adoption, and management aspects in agroforestry (Ellis et al. 2004). Tamubula and Sinden (2000) assessed the sustainability of an agroforestry system in Kenya using the Soil Changes Under Agroforestry (SCUAF) model, an environmental modelling.

As in any other monitored cropping system, also in agroforestry systems special care has to be devoted to the acquisition of input data and their temporal and spatial resolution (Coulson and Stigter 1989; WMO 2008). They are meteorological, physical (soil structure) and cultural (crop cover, etc.) (meta)data. Meteorological data are generally required with hourly time step to better describe the temporal evolution of the risk level (frost, heat, wind), but in several cases (drought, etc.) daily, monthly or annual data can provide enough information. In Vietnam, the application of meteorological and agrometeorological information to planning and management of agroforestry systems has gained in importance as it has intensified day by day (Ngo-Si-Giai 1987).

In other situations (such as fire risk) different time steps are required when the level of risk is due to a specific weather pattern in the presence of severe drought. In Indonesia the Keetch and Byram Drought Index (KBDI) (see also Sect. III.4.5.(β)) is a good proxy for fire risk and may be used as an EWS for agroforestry systems. KBDI is calculated using daily weather data, including rainfall and maximum air temperature as well as annual rainfall (Murdiyarso et al. 2002).

The use of weather forecasts for agriculture and agroforestry is obviously one main theme of EWSs (e.g. Kenyan Meteorological Department 2009). In such cases the full information is represented by the results of the integration between weather monitoring and weather forecast (Dalla Marta et al. 2003). In rather some cases (drought, heat, fire) seasonal climatic forecast, although outside specific years still only marginally successful (see Chap. IV.12), can represent a useful support to elaborate information about the long-term future evolution of the risk (Hartmann et al. 2002).

To increase the spatial resolution of information, the use of GIS has to be considered. Agroforestry suitability analysis will improve as spatial data and computer resources become more accessible. Many states are already assembling internet-accessible GIS data clearinghouses to facilitate the use of spatial information (Bentrup and Leininger 2002). Moreover, micrometeorological studies made already some time ago significant progress concerning weather and climate conditions conducive to pests and diseases that for example affect agroforestry with rubber trees and cocoa crops (De Abreu Sa 1987).

In another example, in Mediterranean countries oak expansion and oak regression is considered a precursor of land conversion and can provide a powerful sign of subtle structural changes (Plieninger and Schaar 2008). Similar assessments could be applied to agroforestry systems comparable to *dehesas*, a traditional, low-input, extensive agroforestry system (Meeus 1995) composed of open, heterogeneous canopies of holm oak (*Quercus ilex*) and cork oak (*Qeurcus suber*) with a shrub or annual herbaceous understorey (Pereira and Da-Fonseca 2003).

Other examples are traditional olive cultivation, chestnut groves, and oak rangelands in Italy, Greece, southern France, and especially on the islands of Sardinia, Corsica, and Crete. If scaled up to a larger area, these modifications of agroforestry systems can be used as an EWS before conversion becomes visible (Plieninger and Schaar 2008). This requires the use of automatic or semi-automatic procedures that extract single trees form remote sensing imagery. Still, given that many traditional agricultural landscapes are highly diverse, specific procedures will have to be developed for each condition (Plieninger and Schaar 2008).

The EWS can be applied directly "on-site", with evident benefits in the assessment of real conditions and microclimate. On the other hand, the management of the advisories and the updating of the system represent big obstacles to services with EWSs. The alternative option, territorial application by extension services or similar organizations, is probably preferable because it allows a better management and updating of the EWS. This solution requires the application of suitable methods for information dissemination among users, taking into account the need for speed.

The further development of ICT will support the realisation and diffusion of EWSs. In Australia, research findings, government reports, and publications on technical and economic aspects of agroforestry should routinely be made available not only in printed form but also on the internet (Black et al. 2000). The use of the latter to form e-mail news groups and other communication networks among agroforesters, extension agents and researchers should also be encouraged. Because agroforestry is a complex enterprise with various possibilities and lengthy time horizons, adoption and management decisions are sometimes difficult.

Reference was made to computer based decision support tools that have been developed to assist in this process, but only a small minority of farmers currently makes direct use of such tools (Black et al. 2000). The use of mobile phones to acquire information is interesting because it enables access from the "field" and does not require the use of computers. SMS warnings can be given in two ways. A "push-type" is sent regularly, that is when criteria are met, and this would be preferable, because "pull-type" ones are sent only on the user's request (Jensen and Thysen 2003). Risk maps and other methods (graphics, tables, etc.) can be used to provide the end users with detailed descriptions of conditions of extreme events (Rijks 1994; Rijks and Baradas 2000; Friesland and Orlandini 2006).

In conclusion the following issues have to be considered in improving the efficiency of EWSs. This applies in general, including agroforestry cases, and they were illustrated in the above case studies:

- Validation of systems, as a whole or for each specific component (weather forecast, meteorological monitoring, models or indices), is not commonly carried out.
- Data are not available or not accurate enough, both for spatial and temporal resolutions wanted.
- Complex systems are not accurate enough in comparison with the empirical rules or the experience acquired and adopted by farmers (see also Chap. IV.4).
- Links between the users and extension services, or in general the organizations issuing the warnings, are too weak.
- The delivery time of information is not fast enough to timely assist decision making.
- Studies on feasible improvements of management practices and estimations of the related cost-benefit decreases through the utilisation of produced information are virtually absent.

References

Bartolini G, Morabito M, Crisci A, Grifoni D, Torrigiani T, Petralli M, Maracchi G, Orlandini S (2008) Recent trends in Tuscany (Italy) summer temperature and indices of extremes. Int J Climatol 28:1751–1760

Bentrup G, Leininger T (2002) Agroforestry: mapping the way with GIS. J Soil Water Conserv 57(6):148–153

Black AW, Forge K, Frost F (2000) Frost extension and advisory strategies for agroforestry. Publication No. 00/184, Project No. ECU-2A, Kingston, 128pp

Coulson CL, Stigter CJ (1989) Appropriateness of instrumentation in agroforestry research in developing countries. In: Reifsnyder WE, Darnhofer T (eds) Meteorology and agroforestry. Proceedings of an ICRAF/WMO/UNEP Workshop on Application of Meteorology in Agroforestry Systems Planning and Management, ICRAF, Nairobi, pp 305–314

Dalla Marta A, Gozzini B, Grifoni D, Orlandini S (2003) Applications of RAMS models for the creation of agrometeorological maps at territorial level. Act of the 6th European Conference on Applications of Meteorology (CD ROM), Rome, 4pp

De Abreu Sa DT (1987) Meteorology applied to agroforestry systems in the Brazilian Amazon region. In: Reifsnyder WE, Darnhofer T (eds) Meteorology and agroforestry. Proceedings of an ICRAF/WMO/UNEP Workshop on Application of Meteorology in Agroforestry Systems Planning and Management, ICRAF, Nairobi, pp 245–255

De Melo-Abreu JP, Daldoum MA, Andrews PL, Bastos TX, De Groot WJ, Fleming R, Fleming R, Fujioka F, Goldammer JG, Govind A, Harrison J, Keenan T, Price D, Statheropoulos M, Stigter K, Wain A (2010) Applications of meteorology to forestry and non-forest trees. Chapter 11 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Ellis EA, Bentrup G, Schoeneberger MM (2004) Computer-based tools for decision support in agroforestry: current state and future needs. Agrofor Syst 61:401–421

Friesland H, Orlandini S (2006) Simulation models and plant pests and diseases. COST Action 718, Meteorology application for agriculture. Office for Official Publications of the European Communities, Luxembourg, pp 81–98

GEO (2008) Global Agricultural Monitoring System. Participating programs. Examples of global to regional agricultural monitoring systems. http://www.earthobservations.org/cop_gams_pp.shtml

Hartmann HC, Pagano TC, Sorooshian S, Bales R (2002) Evaluating seasonal climate forecasts from user perspectives. Bull Am Meteorol Soc 83:683–698

IPCC (2007) Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds)]. Cambridge University Press, Cambridge, UK/New York, 996pp

IRIN (2009) GLOBAL: call for standard indices to measure droughts. http://www.irinnews.org/Report.aspx?ReportId=83323

Jensen AL, Thysen I (2003) Agricultural information and decision support by SMS. EFITA 2003 Conference, Debrecen/Budapest, pp 286–292

Kenyan Meteorological Department (2009) Forecasting services. National Forecasting Centre. Forecasts for the Specialised Fields. http://www.meteo.go.ke/forecast/

Maracchi G (2001) Meteorologia e climatologia applicate [Applied Meteorology and Climatology]. Istituto Geografico Militare, Firenze, 180pp

Meeus JHA (1995) Pan-European landscapes. Landsc Urb Plann 31:57–79

Murdiyarso D (2006) Vegetation and land fire hazards: framing the problems to reduce the risks and disasters. Presented in the Regional Conference on Natural and Human-induced Environmental Hazards and Disasters, Kuala Lumpur. http://www.icsu-asia-pacific.org/resource_centre/inauguration/Session3_Murdiyarso_Veget_Fire.pdf

Murdiyarso D, Widodo M, Suyamto D (2002) Fire risks in forest carbon projects in Indonesia. J Sci China Ser C 45(Suppl):65–74

Ngo-Si-Giai (1987) Climatic resources for agroforestry in Vietnam. In: Reifsnyder WE, Darnhofer T (eds) Meteorology and agroforestry. Proceedings of an ICRAF/WMO/UNEP Workshop on Application of Meteorology in Agroforestry Systems Planning and Management. ICRAF, Nairobi, pp 281–288

Ong CK, Black CR, Wallace JS, Khan AAH, Lott JE, Jackson NA, Howard SB, Smith DM (2000) Productivity, microclimate and water use in Grevillea robusta-based agroforestry systems on hillslopes in semi-arid Kenya. Agric Ecosyst Environ 80:121–141

Orlandini S, Dalla Marta A, Martinelli L (2007) Using simulation modelling as a policy option in coping with agrometeorological risks and uncertainties. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 463–476

Pereira PM, Da-Fonseca MP (2003) Nature vs. nurture: the making of the montado ecosystem. Conserv Ecol 7(3):7. http://www.consecol.org/vol7/iss3/art7/

Plieninger T, Schaar M (2008) Modification of land cover in a traditional agroforestry system in Spain: processes of tree expansion and regression. Ecol Soc 13(2):25. http://www.ecologyandsociety.org/vol13/iss2/art25/

Reifsneyder WS, Darnhofer TO (1987) Meteorology and agroforestry. Proceedings of an ICRAF/WMO/UNEP Workshop on Application of Meteorology in Agroforestry Systems Planning and Management, ICRAF, Nairobi, 554pp

Rijks D (1994) Agroclimatic characterization: Chapter 23. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York, pp 241–244

Rijks D, Baradas MW (2000) The clients for agrometeorological information. Agric For Meteorol 103:27–42

Rosiek S, Batlles FJ (2008) A microcontroller-based data acquisition system for meteorological station monitoring. Energy Convers Manag 49:3746–3754

Stigter CJ (2009) Scientific support to the establishment and validation of agrometeorological services. SciTopics. Research summaries by experts. Elsevier, Amsterdam. http://www.scitopics.com/Scientific_support_to_the_establishment_and_validation_of_agrometeorological_services.html

Tamubula I, Sinden JA (2000) Sustainability and economic efficiency of agroforestry systems in Embu District, Kenya: an application of environmental modelling. Environ Model Softw 15:13–21

Travis JW, Rajotte E, Bankert R, Hickey KD, Hull LA, Eby V, Heinemann PH, Crassweller R, McClure J, Bowser T, Laughland D (1992) A working description of the Penn State apple orchard consultant, an expert system. Plant Dis 76:545–554

WMO (2008) Guide to meteorological instruments and methods of observation, 7th edn. WMO 8, Geneva. Available at the WMO website

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. Brochure prepared by C.J. Stigter. WMO, Geneva, in press

III.5.4 Tactical Decision Making Based on Weather Information

III.5.4.(I) Problems and Solutions in Using of and Coping with Weather Phenomena in Need of Tactical Decision Making and Challenges Remaining for the Use of Science to Contribute to Problem Analyses and Designing Viable Solutions in This Context: Non-forest Trees

Luigi Mariani, Osvaldo Failla, and Kees Stigter

Fruit and vine growing is often an "open sky activity", almost fully exposed to the variability of weather which represents a most important driving factor for final production in terms of quantity and quality. This fact enlightens the importance of a quantitative evaluation of past, present and future behaviour of meteorological variables for tactical choices in fruit culture and viticulture, referred to aspects like (i) cultural measures such as pruning, life removal and replanting, soil works, turf management, etc., (ii) water and nutrients management, (iii) phytosanitary management and (iv) planning of harvest activities and post-harvest activities. Forecasted data can for example be important to plan harvest and post harvest activities, such as for industries for packaging and transformation of fruits or wine industries, that need information to schedule reception activities.

In Sect. III.5.1.(g) we have dealt with frost protection. In this section we want to see the contents also as part of the subject "Develop understanding of the weather phenomena, short and medium range weather forecast, impacts, actions, problems, solutions, policies, and remaining challenges based on case studies". On the base of the validity range after emission (vr), current weather forecasts can be classified in Very Short Range Forecasts (VSRF) (vr = 0–12 h), Short Range Forecasts (SRF) (vr = 12–72 h), Medium Range Forecasts (MRF) (vr = 3–15 days) and Long Range Forecasts (LRF) (vr from 15 days until 3–6 months). In mid latitudes, LRF techniques are not fully established and must be used with extreme caution. Other kinds of forecasts are reliable with a mean accuracy for mid latitudes of 90–95% at 12–24 h, 80–90% at 72 h (3 days) and 65–75% at 6 days (Das et al. 2010). This last

L. Mariani (✉)
Department of Crop Science, University of Milan, Milan, Italy
e-mail: luigi.mariani@unimi.it

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_80,

term is usually considered the operational limit for a useful forecast for orchard and vineyard management. Furthermore a forecast for the second week (7–15 days) can be also useful giving a general tendency.

Frost protection is not only a matter of forecasting skill but also of timely warnings on relevant phenomena. Thus, the usefulness of MRFs with a validity period that enables farmers to organize and carry out appropriate cultural operations to cope with or take advantage of the forecasted weather is warranted. Nowcasting and VSRF of frost is very important for the management of agricultural practices against this event (e.g. low volume irrigation, ground-based fans, trash-fires). In Italy some agrometeorological services used specific Very Short Range Forecast (VSRF) outputs during the period that crops were exposed to risk of late frost (from February to April) or early frost (October and November) (Das et al. 2010).

Nowcasting and VSRF techniques can be applied to many phenomena, but are most frequently used to forecast (WMO 2009): (1) convective storms with attendant phenomena; (2) mesoscale features associated with extra-tropical storms and tropical storms; (3) fog and low clouds; (4) locally forced precipitation events; (5) sand stroms and dust storms; (6) wintertime weather (ice, glazed frost, blizzards, avalanches); and (7) wild fires and contaminated areas. While there is some commonality with synoptic meteorology in forecasting these phenomena, nowcasting focuses greater attention on short time scales and fine spatial resolution covering small geographic areas. It is therefore even more suitable for use in agrometeorological services wherever that is feasible.

In the last years there is a clear tendency to develop the nowcasting of "severe" weather, which requires a special operational routine for the issue of warnings, based on specific regional needs and following specific national or administrative regulations and thresholds (WMO 2009). This will be very applicable to frost forecasting as well. Part II of this book gives several examples were protection measures are taken by farmers after simple foreasts were received. These forecasts may be improved by such new approaches. The adoption of forecasts as management supports must be the consequence of a qualitative evaluation of this information. This evaluation can be carried out by direct analysis of performance data released by NMHSs (see an example in Box III.5.16).

Box III.5.16

An example of operational phenological activity established in Italy from 2006 is represented by the IPHEN project for the production and broadcast of phenological maps for the whole Italian area (Mariani et al. 2007). The adopted thermal models operate on a highly detailed Digital Elevation Model, with pixel of 2×2 km. Thermal fields for maximum and minimum temperature were created applying specific geostatistical procedures to data acquired from the National Agrometeorological Network of CRA (Consiglio per la Ricerca e la sperimentazione in Agricoltura). A standard routine to correct model results on the basis of phenological data collected by a group of observers working in different parts of Italy was implemented. Final results (phenological phases in BBCH scale) are broadcasted on the internet (Mariani et al. 2007). This approach has to be widened in its applications.

The release of the model adopted to forecast the male flowering period of *Cupressus sempervirens* L. and based on thermal units (Torrigiani Malaspina et al. 2007) adopts the following data (Fig. III.5.9):

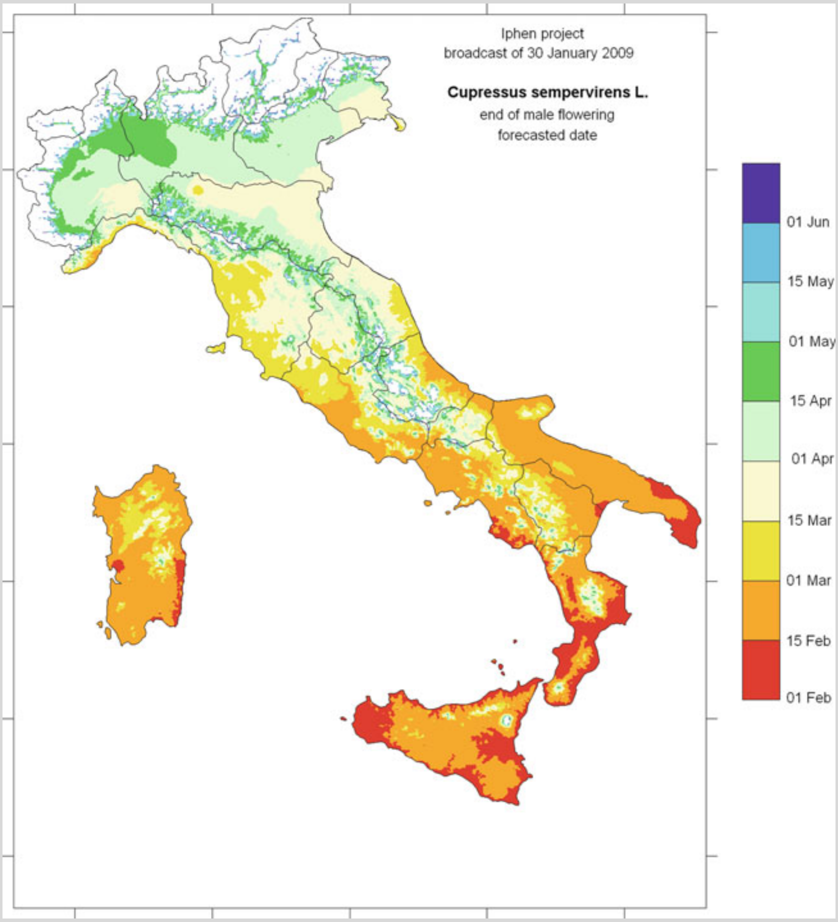


Fig. III.5.9 Forecast of the beginning and end of the male flowering for *Cupressus sempervirens* in Italy. Male flowering begins (*top map*) when 1,151 thermal units have been accumulated (base tempertaure = 0 °C; temperatures exceeding 10 °C are truncated at 10 °C). Male flowering ends (*bottom map*) when 1333 thermal units have this way been accumulated

- past data (until today) coming from the real time network of the National Agrometeorological Network (data from Italian Air Force and CRA Cma);
- forecast data for the next 12 days produced by a NOAA-GFS model;
- climatic data for the next period until cupressus' flowering is concluded.

The same approach, but based on the summation of heating normal hours (Mariani et al. 2007) is applied to simulate the phenological behaviour of:

- two widespread grapevine varieties, the early one Chardonnay, and the late Cabernet sauvignon
- a spontaneous tree, the black elder (*Sambucus nigra* L.).

That we have not always to do with "open sky" situations shows the plasticulture. No technology has modified the course of horticultural crop production as the use of agricultural plastics (Jensen 2004). See also the various sections of Chap. III.6.B. As the Green Revolution expanded the production of agronomic crops, plasticulture has provided yet another revolution. While more silent, plasticulture has enabled countries throughout the world to greatly extend their food production capability. Plastic films and related materials are used extensively to cover greenhouses, high and low tunnels (row covers) and for soil mulches. High tunnels are walk-in hoop structures that are normally unheated and naturally ventilated. See a few more details in Box III.5.17.

Box III.5.17 (Contributed by Kees Stigter)

It is essentially impossible to modify a climatic area, other than by placing the whole growing system under cover. On a small scale, the modification of the environment around the roots and shoots of developing seedlings can extend the growing season and provide many benefits, both in terms of yields and quality. Microclimate modification for low crops can be accomplished through the use of plastic mulches, mini-tunnels or floating row covers (Government of Government of Alberta 2007). For centuries a wide variety of techniques have been used to extend the growing season of horticultural crops. Glass jars, glass cloches, hotcaps, cold frames, hotbeds, and greenhouses of various types have all contributed to season extension.

More recently, row covers and high tunnels have become popular with growers because of their simplicity and effectiveness in protecting crops from low temperatures in both spring and fall. Row covers and high tunnels do not offer the precision of conventional greenhouses for environmental control, but they do sufficiently modify the environment to enhance crop growth, yield and quality of yield. Although they provide some frost protection, their primary function is to elevate temperatures a few degrees each day over a period of several weeks. In addition to temperature control, there are also the benefits of wind and rain protection, soil warming, and in some instances control of insects, diseases, and predators such as varmints and birds. Overall, these growing systems should be considered protected growing systems that enhance earliness and higher yields, improve quality, and reduce the use of pesticides in some cases (Center for Plasticulture 2008).

Row covers and high tunnels have sufficient versatility to make them useful on a wide diversity of crops and in various cropping systems. Vegetables, small fruits, and flowers are all suited to these growing systems; but the specific crops which might be grown will to a large extent depend on marketing opportunities for individual crops by individual growers. High tunnels encompass a crop growing system that fits somewhere between row covers and greenhouses. High tunnels are not conventional greenhouses. But like plastic-covered greenhouses, they are generally quonset-shaped, constructed of metal bows that are attached to metal posts which have been driven into the ground about two feet deep. They are often covered with one layer of greenhouse-grade polyethylene, and are ventilated by manually rolling up the sides each morning and rolling them down in early evening.

There is no permanent heating system although it may be advisable to have a standby portable propane unit to protect against unexpected below-freezing temperatures. There are no electrical connections. The only external connection may be a water supply for trickle irrigation. At Pennsylvania State University a tremendous amount of research and extension programming is oriented toward high tunnel production of vegetables, small fruits, tree fruits and flowers (Center for Plasticulture 2008).

Warm season crops respond the best to these practices. An experiment was performed in Flores da Cunha (Brazil) during the 2005/2006 growing season (Cardoso et al. 2008). It comprised uncovered and covered rows of vines, using a 160 μm thick plastic film. Photosynthetically Active Radiation (PAR), air temperature and humidity, and wind velocity were monitored: over the plastic covering; between the film and the canopy; over the uncovered canopy; and close to grapes of both treatments. Reference evapotranspiration was estimated for both treatments.

From the incoming PAR, almost 68% reached the covered canopy, 16% reached the covered grapes, and 36% reached the uncovered grapes. The plastic covering increased by 3.4 °C the maximum air temperatures close to plants. Diurnal air relative humidity was reduced, while water vapor pressure and vapor pressure deficit were increased because of the plastic covering, which also reduced by 88% the wind velocity in comparison to open air. The reference evapotranspiration of the covered canopy was 35% lower than in open air. Although increasing diurnal air temperatures, the plastic covering may reduce the evaporative demand on vineyards, by reducing the incoming solar radiation and the wind velocity. Modeling such results would be of great assistance through the use of science.

Plasticulture consists of many components, not only plastic but a complete management system that may include pest control, marketing, etc. Plasticulture is a whole system approach to modifying microclimates in producing high quality, high yielding horticultural products (Jensen 2004). In the temperate regions, all methods of protected agriculture are often used for early crop production and to produce summer crops out-of-season, during the winter. Row covers are commonly used during early spring in both the temperate and arid regions, but are seldom used in the tropics. One exception to use in the tropics might be the introduction of non-woven materials as protection against chewing insects or insects which are vectors of plant viruses (Jensen 2004). See Chap. III.6.B. and Box III.5.17 below for more details and a case study.

References

Cardoso LS, Bergamaschi H, Comiran F, Chavarria G, Marodin GAB, Dalmago GA, Dos Santos HP, Mandelli F (2008) Alterações micrometeorológicas em vinhedos pelo uso de coberturas de plástico [Micrometeorological alterations in vineyards by using plastic covering] Revista PAB 43/4. http://webnotes.sct.embrapa.br/pab/pab.nsf/ecd4ca3ff88efcfa032564cd004ea083/8dbb6a8039a7286f83257447004002f2?OpenDocument

Center for Plasticulture (2008) High tunnels. http://plasticulture.cas.psu.edu/H-tunnels.html

Das HP, Doblas-Reyes FJ, Garcia A, Hansen J, Mariani L, Nain A, Ramesh K, Rathore LS, Venkataraman R (2010) Weather and climate forecasts for agriculture. Chapter 5 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Government of Alberta (2007) Microclimate modification with plasticulture. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/faq8266

Jensen MH (2004) Plasticulture in the global community – view of the past and future. http://www.plasticulture.org/history_global_community.htm

Mariani L, Failla O, Dal Monte G, Facchinetti D (2007) IPHEN: a model for real time production of grapevine phenological maps. Proceedings of the Climate and Viticulture Congress, Zaragoza, 10–14 April, pp 272–278. See also www.ucea.it

Torrigiani Malaspina T, Cecchi L, Morabito M, Onorari M, Domeneghetti MP, Orlandini S (2007) Influence of meteorological conditions on male flower phenology of *Cupressus Sempervirens* and correlation with pollen production in Florence. Trees Struct Funct 21:507–514

WMO (2009) Statement of guidance for nowcasting and very short range forecasting. http://www.wmo.int/pages/prog/sat/documents/SoG-Nowcasting-VSRF.doc

III.5.4.(II) Designing and Selecting Weather Related Tactical Applications for Management of Agroforestry and Increasing Their Efficiencies

H.P. Das

Studies conducted in countries such as India have given ample evidence already long ago for concluding that of all the "controls", climate had the greatest effect on the conditions of plants over a series of years (Acuna 1980). In the field of agroforestry, climate information can be used as a basis for tactically determining which species of plants and animals could better survive in an area, in the implementation of cropping patterns in terms of proper combinations of trees and crops. This also applies to the proper timing of cultural and development activities and as a factor that could be considered in planning and implementing a project to ensure effective and economic conduct of different activities (Sapitula 1989). This should remind planners, agriculturists and foresters on the importance of weather related tactical applications for proper management of agroforestry and the need to take all efforts in increasing their efficiencies.

We also know already for a long time that it is essential to understand the relation between climate and the growth phases of woody species for agroforestry systems, as this will help get information on how the plants that are adapted to a particular climate will progress through their various phenological phases in a regular and unimpeded way (Watts Padwick 1979; Huxley 1983). Species will vary in these patterns of response, but each can be expected to behave according to the particular strategy inherent in the patterns originally established at its centre of origin.

Thus regulatory conditions will be triggered by appropriate climatic conditions to result in leaf initiation, bud development and leaf expansion at an appropriate part of the season, and similarly for flower initiation, anthesis, pollination, fertilization and fruit growth and maturation. If a woody species is ill-adapted, then it is usually clear at an early stage that the sequence of phenological phases is not properly entrained to climatic variations, because it behaves in a way that suggests that it will not be able to make good use of the climatic pattern in which it now finds itself (Huxley et al. 1989). It may then be possible, by using suitable management practices like lopping

H.P. Das (✉)
Retired from Indian Meteorologidal Department, Pune, India
e-mail: hpd_ag@rediffmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_81,

or pruning, to adjust the sequence of phases to a more suitable entrainment, and the phenological information gained by studying its behaviour in the field will provide information about the best times at which to make such management interventions.

Manipulation of environmental stress by controlling exposure is another way to modify phenological behaviour. Shading will also affect the sequence of phases and thus prolong the vegetative phase (Stigter 1984, 1994). For detailed understanding of shading aspects, see Box III.5.18.

Box III.5.18

There is ample evidence that seed and fruit producing trees are often of a shade intolerant type, as observed by Jackson (1989). They can not produce in the more shaded parts of the trees and consequently there has been a pronounced move towards using dwarfed trees giving shallow and well illuminated cropping canopies. The productivity gain in the sole crop orchard is a result of better illumination of the fruiting wood, easier and cheaper management as a result of the reduced tree size (Jackson 1985) and a lower respiratory load in relation to photosynthetic productivity. In the agroforestry situation there would be a tremendous additional advantage of eliminating the non-productive zones of fruit and seed producing trees in that this would enable light currently intercepted unprofitably by the lower and inner parts of such trees to be available for growing understorey crops.

The simplest approach to meeting the specific agroforestry objective is to produce vertical columnar trees capable of producing fruits (Tobutt 1985) all the way down to ground level. This would mean that there is little unproductive inner zone. Such trees would minimize F_{max} (i.e. the decimal fraction of the available light which would have been intercepted if the trees were "solid") for any given level of fruit production, minimize light interception per unit tree LAI, and maximize availability to the intercrop at ground level.

There are two ways of achieving such tree form, by selection and breeding; and by pruning (Jackson 1989). Even when the trees are of the right type (maintaining linear relationship between economic yield and light intensity) in their light response, it is clearly advantageous in an interspersed agroforestry situation for the timber trees to have a maximum ratio of economic yield (trunk) to tree volume and cast-shadow area (F_{max}).

It is likely to be most difficult to put into effect where the ground crops have specific shade requirements. In general it is much easier to ensure an even low level of irradiation in the understorey if the trees have high F_{max} and low leaf area per unit canopy volume, grown as flat-headed (umbrella-like) trees or as very tall thin hedgerows. It is much more difficult if they are dense and columnar with low F_{max} and high density of shading; although this can be achieved in row systems and alley systems with appropriate dimensions and row orientations (Jackson and Palmer 1989).

The ideal understorey crop or alley crop to combine with dense columnar spaced trees is one with a light response so that it can make use both of very high irradiances in unshaded areas and low irradiances close to the trees. Jackson and Palmer (1989) showed that row systems and alley systems can result either in relatively uniform shade across the alley or in a combination of dense shade near the trees and little shade in the alley centre or adjacent to a south-facing row (if north of equator). Moreover, the shade pattern can change with the time of year. The uniformity of shade cast by scattered or evenly distributed trees will depend on the height of their foliage above the ground as well as on their LAIs. Under these circumstances the efficiency with which a crop can utilize the light which is not intercepted by the trees will depend on the combination of crop requirements and light intensity patterns over space and over time.

Other management practices or situations that can influence the phenology of woody plants in the tropics are those that can indirectly affect stress patterns arising out of climatic variations. For example, planting density, choice of site to affect exposure or shelter, aspect, slope (in as much as it affects run-off and soil water) and, of course, the intercropping association of woody perennials with crops and/or grasses (Huxley et al. 1989).

In order to optimize the integrated agroforestry system, it is essential to know the proportion of the total light which will be available to the ground crop(s) and its distribution over the cropped area. It may well be preferable to have the entire crop surface irradiated as uniformly as is possible, or to have a system with more shade-tolerant ground crops planted nearest to the trees (Jackson 1989) (for more details see Box III.5.18). In a microclimatic study of an agroforestry system in the hilly region of West Bengal, India, Mukherjee et al. (2008) identified favourable environmental factors as well as suitable shade trees for the better growth and yield of tea.

One of the serious limitations in agroforestry systems in some regions is the occurrence of wet-season dry spells which may last from a few days to more than three weeks. In the absence of any large-scale irrigation scheme, which is unlikely to be a universal practice in the near future, these dry spells cause severe damage to shallow rooted crops and grass (Garrido et al. 1979; Lal 1991), though tree species are generally capable of utilizing the subsoil moisture. Suitable agroforestry systems should offer some security against total loss of income, especially in the case of small farmers (Zhao et al. 2005). See also Box III.5.19 and various sections in Sub-chapter III.3.

Selection of suitable perennial crops tolerant to such water stress from dry spells (and adapted to low soil fertility and high soil acidity) could be one of the useful strategies in this regard (Haridasan 1989; Das 2004). Traditional fruit trees like

Box III.5.19

The tactical use of windbreaks to afford protection to crops under agroforestry systems is very common in many parts of the world (Stigter 1985; Brandle et al. 1988; Stigter et al. 1989, 2002). As example, windbreaks are frequently used in the Mediterranean region of Europe, to protect crops tactically from the cold spring winds during the flowering season and strategically from the strong westerly winds throughout the year as well as from the blasting effect of the sea. The trees most commonly used as wind breaks are cypress, various species of eucalyptus, casuarinas, tamarix, the wattle tree and, to a lesser degree, pines (Leontiades 1989). The planting is usually done in two rows along the boundary of the holding and the trees are staggered in the two rows. The planting distance between the trees varies from 0.5 to 2.0 m depending on species and on the degree of protection required.

Properly oriented and designed shelterbelts are very effective in stabilizing production in agroforestry, particularly in the regions where adverse weather conditions cause damage and impose severe stress on growing crops (Mohammed 1991; Stigter 1994; Das 2005; Wang et al. 2007). For example in Cyprus the existence of large continuous stretches of State Forests on the upper catchments of practically all the watersheds provides huge continuous shelterbelts that create protection to agricultural lands lower down in the watershed and especially to the land in the neighboring foothills (Leontiades 1989). However, this use may have to be seen as a strategical measure. The protection consists in the amelioration of the microclimate; the reduction of extremes in low and high temperatures; the protective effect on plants and animals from the cold winds and the frost of winter; and the protection against soil erosion through the action of water that would come down the steep slopes dangerously had they not been clothed with the forest vegetation (Easterling et al. 1997; Eitzinger et al. 2007).

mango, citrus and guava, as well as other native species which could be exploited on a commercial scale, should be one of the options. According to Das (2003), agroforestry can be an integral part of any dryland development strategy for sustainable agricultural resources, as long as the right species of plants are tactically selected, on the basis of climate information, and then rationally managed.

References

Acuna RC (1980) The national agricultural weather service – making weather work for the Filipino farmer. PAGASA, Quezon City, 27pp

Brandle JR, Hintz DL, Sturrock JW (1988) (eds) Windbreak technology. Elsevier, Amsterdam, 597pp

Das HP (2003) Adaptation strategies in agriculture to cope with the impacts of climate change and climate variability on agriculture. Report of the RA II working group on agricultural meteorology. CAgM Report 88, WMO/TD 1111, Geneva, pp 59–117

Das HP (2004) Adaptation strategies required to reduce vulnerability in agriculture and forestry to climate change, climate variability and climate extremes. In: Management strategies in agriculture and forestry for mitigation of greenhouse gas emissions and adaptation to climate variability and climate change. Technical Note 202, WMO 969, Geneva, pp 41–92

Das HP (2005) Agrometeorological impact assessment of natural disasters and extreme events and agricultural strategies adopted in areas with high weather risks. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin/Heidelberg, pp 93–118

Easterling WE, Easterling MM, Brandle JR (1997) Modelling the effect of shelterbelts on maize productivity under climate change: an application of the EPIC model. Agric Ecosyst Environ 61:163–176

Eitzinger J, Utset A, Trnka M, Zalud Z, Nikolaev M, Uskov I (2007) Weather and climate and optimization of farm technologies at different input levels. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 141–170

Garrido WE, Silva EM, Jarreta Jr. MH, Souza OC (1979) Water-use efficiency by wheat varieties in a Cerrado soil of Brazil. In: Lal R, Greenland DJ (eds) Soil physical properties and crop production in the tropics. Wiley, Chichester, etc, pp 215–225

Haridasan M (1989) Agroforestry systems for the cerrado region of central Brazil: potentials and constrains. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 257–272

Huxley PA (1983) Phenology of tropical woody perennials and seasonal crop plants with reference to their management in agroforestry systems. In: Huxley PA (ed) Plant research and agroforestry. ICRAF, Nairobi, 617pp

Huxley PA, Akunda E, Darnhofer T, Gatama D, Pinney A (1989) Tree/crop interface investigations: preliminary results with *Cassia siamea* and maize. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 361–370

Jackson JE (1985) Future fruit orchard design: economics and biology. In: Cannell MGR, Jackson JE (eds) Attributes of trees as crop plants. Institute of Terrestrial Ecology, Natural Environmental Research Council, Huntington, pp 441–459

Jackson JE (1989) Tree and crop selection and management to optimize overall system productivity, especially light utilization, in agroforestry. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 163–173

Jackson JE, Palmer JW (1989) Light interception at the tree/crop interface. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 391–400

Lal R (1991) Myths and scientific realities of agroforestry as a strategy for sustainable management of soils in the tropics. Adv Soil Sci 15:91–137

Leontiades L (1989) Traditional agroforestry practices under the edaphoclimatic parameters of Cyprus. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 233–240

Mohammed EA (1991) The influence of a Eucalyptus-shelterbelt on sand movement in North-West Gezira, Sudan. Ph.D. thesis, University of Gezira, Wad Medani, Sudan, xvii+370pp

Mukherjee A, Banerjee S, Nanda MK, Sarkar S (2008) Microclimate study under agroforestry system and its impact on performance of tea. J Agrometeorol 10:99–105

Sapitula BP (1989) The need for climatic information for agroforestry systems in the Philippines. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 289–294

Stigter CJ (1984) Traditional use of shade: a method of microclimate manipulation. Arch Meteorol Geophys Biocl B 34:203–210

Stigter CJ (1985) Wind protection in traditional microclimate management and manipulation: examples from East Africa. In: Grace J (ed) The effects of shelter on the physiology of plants and animals. Progress in biometeorology 2, Swetz and Zeitlinger, Lisse, pp 145–154
Stigter CJ (1994) Management and manipulation of microclimate. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York/Oxford, pp 273–284
Stigter CJ, Darnhofer T, Herrera SH (1989) Crop protection from very strong winds: recommendations from a Costa Rican agroforestry case study. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 521–530
Stigter CJ, Mohammed AE, Al-amin NKN, Onyewotu LOZ, Otengi SBB, Kainkwa RMR (2002) Agroforestry solutions to some African wind problems. J Wind Eng Indust Aerodyn 90:1101–1114
Tobutt KR (1985) Breeding columnar apples at East Malling. Acta Hort 159:63–68
Wang S, Ma Y, Hou Q, Wang Y (2007) Coping strategies with desertification in China. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 317–341
Watts Padwick G (1979) Growth phases in plants and their bearing on agronomy. Exp Agric 15:15–26
Zhao Y, Wang C, Wang S, Tibig LV (2005) Impacts of present and future climate variability on agriculture and forestry in the humid and sub-humid tropics. Clim Change 70:73–116

III.5.5 Developing Risk Management Strategies

III.5.5.(α) Defining, Managing and Coping with Weather and Climate Related Risks in Agroforestry

H.P. Das

The areas where trees and crops modify each other's biophysical environment can be thought of as the tree/crop interface. It is there that they compete for growth resources such as light, water and nutrients, three "resource pools" exploited by the components of agroforestry systems (Huxley 1983). Generally the interactions are complex, either positive or negative, and they result in services rendered and/or competitive effects (Stigter and Baldy 1993). In order to optimize the interactions in tree/crop combinations, it is necessary to understand, and therefore to define and quantify, changes in radiation regime, wind field and rainfall partitioning due to the trees as obstacles in agricultural crop land and interception by canopy and stem of the trees. Darnhofer et al. (1989) quantified the latter changes.

The possibility of maximizing overall productivity by combining trees of high transmissivity but high light requirements for development of their economic product with ground crops with lower light requirements was considered (Jackson 1989; Jackson and Palmer 1989). For details see the previous Sect. III.5.4.(II). For fodder tree species, lopping done for harvesting forage periodically can at the same time increase light availability to undergrown crops and improve their performance.

In agroforestry systems, microclimate amelioration results primarily from the use of trees for shade (Stigter 1994; Mukherjee et al. 2008), live-fences or windbreaks and shelterbelts (Stigter et al. 1989, 2002; Das 2005; Wang et al. 2007). The evidence for the beneficial effects of shade trees depends upon the nature of the understorey crops. The clearest effects were reported for crops that require shading for normal growth, such as black pepper, turmeric etc. (e.g. Pathak et al. 2006).

Tree shading can thus prevent frost damage to crops and reduce nocturnal radiation cooling on the crop surfaces. Other frost protection methods, such as covering plants with sheets and foils, are also used in small plots for low input systems. Long-term measures that are very important for avoiding damage to crops from

H.P. Das (✉)
Retired from Indian Meteorologidal Department, Pune, India
e-mail: hpd_ag@rediffmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_82,

radiation frost include planning of plantations in relation to topography, in order to avoid impacts from cold air lakes (Eitzinger et al. 2007). A reduction in vapour pressure deficit will cause a reduction in transpiration and hence reduce water stress for intercrops. This is especially beneficial during short periods of drought (see Box III.5.20) and may result in increased production. Examples of a buffering effect of trees on microclimate beneath them are for example reported for combinations of coconut and cocoa, millet and leucaena, mustard and soybean with hardwickia and tea with paulownia (Pathak et al. 2006).

Box III.5.20

Haridasan (1989) discussed occurrences of dry spells during the rainy season and its impact on agroforestry practices in the Cerrado region of central Brazil. It has been observed that wet season dry spells could be very damaging if they coincide with critical growth stages such as flowering. Besides guaranteeing an alternative source of income for small farmers, one of the possibilities that should be exploited in agroforestry systems for the Cerrado region is minimizing evapotranspiration demand by providing shade or reducing wind velocity. Since the water-holding capacity of the Cerrado soils is one of the limiting factors, contributing to crop failures during wet season dry spells, improving the water retention characteristics of these soils should be one of the aims of better management systems. Long-term crop rotation with fast growing tree species could increase the organic matter content of these soils and thus minimize the consequences of wet-season dry spells. It is also suggested to exploit the possibilities of utilizing native species which are adapted to the climate and low soil fertility. It is well established that the Cerrado tree and shrub species have extremely deep root systems, capable of utilizing subsoil moisture during the dry season, and have several weather related adaptive strategies to resist fires which are frequent in the region (Haridasan 1989).

Salinger et al. (2005) reported that due to increasing climate variability under extreme climatic conditions in the arid and semi-arid tropics, for example physiologically critical temperature thresholds for crops were attained more frequently. Agroforestry systems offer the most effective option and solution to this problem as a long term measure and can be an integral part of any dryland development strategy (Das 2003; Eitzinger et al. 2007). To overcome the serious lack of fodder in native pastures of arid and semi-arid lands during the long dry season, silvopastoral combinations involving forage shrubs and forage trees should be a viable practice in this respect (Das 2004).

References

Darnhofer T, Gatama D, Huxley PA, Akunda E (1989) Rainfall distribution at a tree/crop interface. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 371–382

Das HP (2003) Adaptation strategies in agriculture to cope with the impacts of climate change and climate variability on agriculture. Report of the RA II Working Group on Agricultural Meteorology. CAgM Report 88, WMO/TD 1111, Geneva, pp 59–117

Das HP (2004) Adaptation strategies required to reduce vulnerability in agriculture and forestry to climate change, climate variability and climate extremes. In: Management strategies in agriculture and forestry for mitigation of greenhouse gas emissions and adaptation to climate variability and climate change. Technical Note 202, WMO 969, Geneva, pp 41–92

Das HP (2005) Agrometeorological impact assessment of natural disasters and extreme events and agricultural strategies adopted in areas with high weather risks. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin, etc, pp 93–118

Eitzinger J, Utset A, Trnka M, Zalud Z, Nikolaev M, Uskov I (2007) Weather and climate and optimization of farm technologies at different input levels. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, Berlin, etc, pp 141–170

Haridasan M (1989) Agroforestry systems for the Cerrado region of central Brazil: potentials and constrains. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 257–272

Huxley PA (1983) Phenology of tropical woody perennials and seasonal crop plants with reference to their management in agroforestry systems. In: Huxley PA (ed) Plant research and agroforestry. ICRAF, Nairobi, 617pp

Jackson JE (1989) Tree and crop selection and management to optimize overall system productivity, especially light utilization, in agroforestry. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 163–173

Jackson JE, Palmer JW (1989) Light interception at the tree/crop interface. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 391–400

Mukherjee A, Banerjee S, Nanda MK, Sarkar S (2008) Microclimate study under agroforestry system and its impact on performance of tea. J Agrometeorol 10:99–105

Pathak PS, Solanki KR, Rai P, Handa AK, Pateria HM (2006) Agroforestry. In: Handbook of agriculture. Indian Council of Agricultural Research, Director of Information and Publication of Agriculture, New Delhi, pp 1076–1127

Salinger MJ, Sivakumar MVK, Motha R (2005) Reducing vulnerability of agriculture and forestry to climate variability and change: workshop summary and recommendations. Clim Change 70:341–362

Stigter CJ (1994) Management and manipulation of microclimate. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, New York/Oxford, pp 273–284

Stigter CJ, Baldy CM (1993) Manipulation of the microclimate by intercropping: making the best of services rendered. In: Sinoquet H, Cruz P (eds) Ecophysiology of tropical intercropping. INRA, Paris/Guadeloupe pp 29–44

Stigter CJ, Darnhofer T, Herrera SH (1989) Crop protection from very strong winds: recommendations from a Costa Rican agroforestry case study. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. ICRAF/WMO/UNEP, Nairobi, pp 521–530

Stigter CJ, Mohammed AE, Al-amin NKN, Onyewotu LOZ, Otengi SBB, Kainkwa RMR (2002) Agroforestry solutions to some African wind problems. J Wind Eng Indust Aerodyn 90: 1101–1114

Wang S, Ma Y, Hou Q, Wang Y (2007) Coping strategies with desertification in China. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, Berlin, etc, pp 317–341

III.5.5.(β) Developing Scales and Tools for Weather and Climate Related Risk Quantifications in Agroforestry

Kees Stigter and Kulasekaran Ramesh

Similar to forestry, weather and climate related risks in agroforestry may broadly be arranged in three types of risks viz., instant risk, creeping risk and cumulative risk (see Sect. III.4.5.(β)) Interactions in agroforestry systems take place mainly via microclimate, sharing of soil and sharing of soil resources. Agroforestry has a particular potential to help check or reverse degradation of soil, forest and pasture resources. Agroforestry systems could be designed to suit virtually any set of environmental conditions in the tropics and subtropics. The greatest potential contribution that particularly indigenous agroforestry makes is through tree management in densely populated steep lands (Young 1987; Tiffen et al. 1994). Kusumandari and Mitchell (1997) concluded from a model based study that agroforestry was an optimal land use to minimize soil loss.

There is a wealth of literature on agroforestry systems related to physiological and ecological aspects, but the literature on weather and climate related risk quantifications is very meager and seen as the combination of quantifications for cropping systems (Sects. III.2.5.(β) and III.3.5.(β)) and tree systems (III.3.5.(β)). In all these works, as we reported earlier, risk quantifications do not go beyond useful but limited statistics on occurrence of disturbing factors and on various categories of observed damages and resiliencies, but it sometimes includes resistance scales (e.g. Warrilow 1999).

For example a lack of knowledge was noted by Wisse and Stigter (2007) in developing regions, of the aerodynamic properties of local biological shelter, such as often utilized in African agroforestry (Stigter et al. 2005). Lack of such quantifications has been explained in Chap. IV.9. It is also clear from other literature searches that quantitative approaches in agroforestry are found much more in developed than in developing countries (e.g. http://aust-repos-census.usq.edu.au/the-fascinator/search/default/agroforestry) and of course also within international organizations operating in developing countries, of which the lengthy case in Box III.5.21 is an example.

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_83,

Box III.5.21 (Contributed by Kees Stigter)

The Ganges Basin is subject to a monsoonal climate regime, with a large proportion of its annual precipitation occurring within the summer months. A wide range of values for the temperature and precipitation is combined with a high spatial variability along a gradient from south to north across the study area. Although the mean precipitation value is close to 950 mm, precipitation ranges from 490 mm in the dry south to 1,830 mm near the Himalayan foothills. Potential evaporation (mean = 1,665 mm) is relatively high, reflecting a generally warm sunny climate with very high temperatures before the onset of the monsoon.

Climatic variables were analyzed using an Aridity Index (AI) modeled spatially to quantify precipitation deficit over atmospheric water demand. In an earlier global study of hydrologic impact of afforestation, optimal bioclimatic zones for afforestation and reforestation were found to be above the threshold of AI = 0.65. This value approximates the lower threshold for a semi-arid moisture regime that can support rainfed agriculture with more or less sustained levels of production. More than 82% of the study area has an AI below 0.65, indicating the severity of water scarcity for agricultural production in this region, before the investment in a widespread irrigation infrastructure.

The annual Actual Evapotranspiration (AET) predicted for an irrigated poplar agroforestry system ranges from 1,780 to 1,940 mm, with a mean of 1,840 mm. This compares with a regional mean of 1,685 mm. The increase in annual AET resulting from agroforestry averages around 177 mm, roughly a 10% increase in annual vapour flows, with maximum values being as high as 16%. This is in agreement with a study on boundary plantings of poplar adjacent to wheat, which showed an increase in water use from 7.5 to 12.7% in 4-year old plantations along a gradient from the tree line to the adjacent crop.

In the case of the model used, results are based on an idealized tree crop rotation over a 10-year cycle, so that the estimates are calculated as an average value of annual AET over the 10-year rotation period. This assumption is used to scale-up the model to incorporate the fact that the poplar identified within the landscape as agroforestry could be at any point along that 10-year time cycle (but likely to be at least 3 years old if identified by the forest canopy density analysis). High levels of AET occur only during the last half to two-thirds of the 10-year rotation, and only during full leaf and not during winter dormancy.

As a result, the average values reflect the negligible contribution of poplar to annual AET during the early years of the agroforestry rotation. The equivalent mean annual increase in AET across the entire agricultural zone resulting from agroforestry, with agroforestry extent at the current 10% of agricultural area, is only 18 mm, i.e., a mere 1.1% of annual vapour flows. Even with full adoption, that is, even if the entire agricultural area adopted agroforestry, the total increase in annual vapour flows would still only be 10.4%. Since poplars and various other trees grow rapidly and transpire large amounts of water, hydrological effects of poplar-based agroforestry and other tree-based systems are, in general, expected to be significant with potential consequences for adjacent crop production and downstream users. Generally, non-orchard trees within the agricultural landscape are viewed as using water in situ, directly competing with agricultural production and/or lowering overall water use efficiency.

Poplar agroforestry presents a different set of circumstances, in that it is planted on irrigated land, either replacing or complementing a high input, intensive, irrigated rice/wheat cropping system. The relatively minor increase in the vapour flow associated with the conversion to agroforestry is further diminished at the landscape level, with only 10% of land currently under agroforestry. As a result, the increased vapour flow across the region resulting from the adoption of agroforestry is estimated to be minimal, although locally it can range as high as 16%. The deciduous phenology of poplar contributes considerably to its low impact on water use, with a dormancy period that corresponds with the peak growth of the winter (or dry season) crop. Likewise, this deciduous phenology minimizes the annual AET, and particularly reduces the irrigation requirement of the poplar component within the farming system.

Considering the contribution of poplar to the local economy and farmer livelihoods, this represents a relatively low-cost improvement in productivity when evaluated in terms of water use. Results indicate that the widespread adoption of poplar agroforestry has created an improvement in the water productivity of this region. In particular, it was found that boundary plantings had little or no impact on regional water use, but could add significantly to “farmer livelihood and economic security”. The importance of growing trees outside of forests, in general, for domestic and industrial uses, and growing trees on-farm, in particular, has been shown. Overall, these results illustrate a potential for meeting the increasing global demand for wood from trees grown on-farm in irrigated agroforestry systems.

The high spatial variability found in the results of the analytic modeling highlights the potential use of this modeling approach by land use managers, for example, to assess the impact of promoting new plantations within specific regions and areas. The modeling approach was cost-effective and timely but would benefit from validation and calibration of results through hydrological fieldwork. Preliminary comparison with global data sets of runoff showed a good correspondence with the model results. Future efforts should calibrate this modeling approach with water use measurements, e.g. using sap flow devices, or ground measurements of water use, to improve validation and calibration of results, both locally and globally. See also Chap. IV.9.

The material for this Box was largely taken from Zomer et al. (2007).

Planting windbreaks is a long-term risk reducing investment for landowners. The benefits of planting a windbreak can be increased by creating a multipurpose windbreak. A multipurpose windbreak is designed to provide multiple functions and/or products, in addition to wind protection. Multiple products or uses from a windbreak can include fruit, timber, animal fodder, wildlife habitat, and other economic or farm products. Adding multiple functions or products to a windbreak can make the installation and management more satisfying and economically viable for the landowner. Multipurpose windbreaks require additional care in planning and management to maintain the primary function of wind protection as an instant risk while maximizing secondary yields. Although results are variable, there are a number of (again) statistically documented cases in the mainland US of risk reducing windbreaks improving property value with 6–12%, crop production with 6–44%, changes in working conditions, equipment/structure maintenance in a variable way, while noise levels reduced with 10–20% and wind erosion reduced with 50–100% (Wilkinson and Elevitch 2000).

Hamilton (1986) suggested already more than twenty years ago that with high performance standards, direct wood product harvest and stable shifting agriculture do not significantly increase the incidence nor severity of major catastrophic lower basin floods, and may result in greater yield of water from the watershed through reduction in evapotranspiration losses. There are many watershed benefits to be garnered from introducing trees or groups of trees into agricultural or grazing systems. It is cautioned, however, that these benefits in soil and water protection do not occur automatically by virtue of having trees on the land. For instance, there can still be erosion and resulting sediment in an agroforestry system, if the crop cultivation is not carried out with good soil conservation management practices, including such things as terraces in steep land and maintenance of organic litter or live vegetation on the otherwise bare soil.

There are many excellent reasons for maintaining forests or for planting forests or trees on watershed lands. These relate not only to the direct product benefits, to biological diversity conservation, and to landscape aesthetics, but to a bundle of very practical, though difficult to quantify, cumulative benefits having to do with erosion risks and hydrologic safety in a watershed management context. It is important, however, for foresters and other watershed professionals not to make unrealizable claims of mythical or questionable soil and water benefits (Hamilton 1986).

Under creeping risks, drought may be described as a chronic natural disaster characterized by prolonged and abnormal water shortage. The drought scales and tools earlier discussed for forestry (Sect. III.4.5.(β)) also apply to agroforestry. An Aridity Index (AI) approach as treated there was used recently by Zomer et al. (2007) to determine the necessity for irrigation systems in northern India. They give a lengthy quantitative case study on using our whole gamma of evapotranspiration calculations, using the FAO approach (Allen et al. 1998), together with quantification of tree densities. This example proves that poplar agroforestry introduction under irrigated conditions in the climate of northern India leads only to small increases in water consumption and an increase in water productivity and income. It is therefore a low-cost low-risk agroforestry intervention (Box III.5.21).

References

Allen RG, Pereira LS, Raes D, Smith M (1998) Evapotranspiration – guidelines for computing crop water requirements. Irrigation and Drainage Paper 56, FAO, Rome. http://www.fao.org/docrep

Hamilton LS (1986) Towards clarifying the appropriate mandate in forestry for watershed rehabilitation and management. In: Strategies, approaches and systems in integrated watershed management. FAO Conservation Guide 14, Rome. http://www.fao.org/DOCREP/006/AD085E/AD085e06.htm

Kusumandari A, Mitchell B (1997) Soil erosion and sediment yield in forest and agroforestry areas in West Java, Indonesia. J Soil Water Conserv 52:376–380

Stigter CJ, Onyewotu LOZ, Al-Amin NKN (2005) Wind and agriculture; an essential subject of the African Participatory Research Agenda. Paper #103. In: Naprstek J, Fischer C (eds) Proceedings of the 4th European & African Conference on Wind Engineering, ITAMAS, Prague, 11pp

Tiffen M, Mortimore M, Gichuki F (1994) More people, less erosion. Environmental recovery in Kenya. Wiley, New York, 311pp

Warrillow MP (1999) Ecological impact of glaze storm damage in an Appalachian oak forest. M.Sc. thesis submitted to Virginia Polytechnic Institute and State University. www.scholar.lib.vt.edu/theses/available/etd-031999-145749/unrestricted/etd.PDF

Wilkinson KM, Elevitch CR (2000) Multipurpose windbreaks: design and species for Pacific islands. Agroforestry Guides for Pacific Islands 8, 32pp. http://www.agroforestry.net/pubs/multwind.pdf

Wisse JA, Stigter, K (2007) Wind Engineering in Africa. J Wind Eng Indust Aerodyn 95:908–927

Young A (1989) The environmental basis of agroforestry. In: Reifsnyder WS, Darnhofer TO (eds) Meteorology and agroforestry. Proceedings of an International Workshop on The Application of Meteorology to Agroforestry Systems Planning and Management, ICRAF, Nairobi, 9–13 February 1987, pp 29–48

Zomer RJ, Bossio DA, Trabucco A, Li Yuanjie, Gupta DC, Singh VP (2007) Trees and water: smallholder agroforestry on irrigated lands in Northern India. IWMI Research Report 122. International Water Management Institute, Colombo, Sri Lanka, 47pp. http://www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/PUB122/RR122.pdf

III.5.5.(γ) Improving Weather and Climate Related Risk Assessments for Non-Forest Trees

C.J. Stigter, H.P. Das and Kulasekaran Ramesh

Scientific evidence is now available to show that the spatial and temporal heterogeneity created by agroforestry plantings can help enhance resources, increase production, reduce risks of monocultural agricultural and forestry practices, and achieve system stability and sustainability. Previous sections in this chapter have shown this. In summary, the biological advantages of agroforestry in risk assessments are increased site utilization; improved soil characteristics; increased productivity; reduced soil erosion; reduced microclimate extremes; positive use of microclimate changes; enhanced above- and below-ground biodiversity (Ruark et al. 2003).

From a risk reduction point of view, apart from reducing the demand for forest tree products by replacing forest resources with equivalent on-farm resources, agroforestry can sustain and improve crop yields as well as providing a range of additional resources and services. By utilizing trees for animal fodder and green manure, the integration of trees into crop and animal systems can introduce substantial nutritional inputs. Trees also have the potential to maintain and improve structural and nutritional properties of soils through nitrogen fixation, soil aeration, contributions to the organic matter content and structural stability of the soil.

In addition to this, agroforestry can contribute towards the satisfaction of subsistence needs (e.g. food, fuelwood, timber), supplement incomes (sale of raw or processed tree products), replace farm inputs which would otherwise be purchased (e.g. green manure, live-fencing) and provide social benefits such as boundary demarcation, shade and privacy (Reed 2000). These issues have also been widely discussed in Chap. III.3 and other sections of this Chap. III.5. We give some examples of details to be known for risk assessments below.

The past two centuries have seen a worldwide shift from low input/low output agriculture to more intensive farming systems. This shift is still on for all sorts

C.J. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_84,

of agricultural production including output from non-forest trees. To ensure that the shift results in sustainable agricultural production, there is a need for better risk assessments among the growers communities on the implications of increasing climate variability and climate extremes in farming systems with non-forest trees such as rubber, oil palm, coffee, cocoa, citrus fruits, grape, coconut and other plantation/orchard trees.

The growth of the plantation trees mentioned above depends largely on rainfall amount and pattern, temperature and the intensity of the winds. As to the latter, windthrow, being a natural phenomenon affecting forests, is also a serious risk in agroforestry. The windthrow hazard classification scheme approach for identifying when wind damage is most likely to occur (Stathers et al. 1994) could be successful in agroforestry too.

Among these trees, oil palm appears to be able to stand a longer period of dry weather but the effect of prolonged drought has been known to reduce the yield of the crop. It has been observed in Africa and South America that low yields of oil palm coincide with the dry season and high yields with the beginning and middle of the wet season (Chan 2001). Low temperatures inhibit the growth of oil palm, particularly the young seedlings whose growth is totally inhibited at 15 °C.

The production of coconut depends especially on rainfall and moderately on temperature (Gurusamy et al. 2008; Ghosh et al. 2005). In India, coconut palms, as rainfed crop, are prone to drought of different intensities and durations leading to significant reduction in yields. Drought management involves planting drought resistance cultivars, drip irrigation and soil moisture conservation practices (Rajagopal and Naresh Kumar 2005). Cocoa trees have been known to be able to withstand temperatures well above 31 °C for short periods and growth is markedly reduced if the temperature dips below 18 °C (Owusu-Manu 1996). Excessive rainfall causes high disease incidence in cocoa crops, especially phytophthora and pink diseases (Zhao et al. 2005).

Another example is the coffee crop which needs adequate rainfall from pinhead to bud formation. The effect of water deficit on this crop during the dry spells is 2-fold. During the bud dormancy period water deficit has a positive effect, preparing the crop for the next flowering stage. However, if a dry spell occurs during either the pinhead or the granulation periods, the yield will be reduced (Chan 2001). The impacts of drought on these plantation crops may also be reduced through using wider spacing (Maracchi et al. 2005).

Examples of instituted adaptation strategies (to the risks and challenges of climate variability and change) include use of drought resistant/genetically modified organisms (see Box III.5.22), crop diversification, adoption of improved farming technologies (agroforestry, improved fallows, integrated pest management), reduction of water loss through water conserving technologies, promotion of rainwater harvesting, use of efficient and non-polluting sources of energy (LPG, solar cookers) and policy reforms to control environmental degradation (e.g. deforestation). However, some of the strategies remain expensive and largely inaccessible to the majority of the poor in Africa. In addition, in most cases comprehensive adaptation policy measures are yet to be adopted (CSD 2005). (See also Box III.5.22.)

Box III.5.22 (Contributed by C.J. Stigter)

Agricultural research, including transgenic research, needs to focus on African realities and needs (UNEP 2006). African agriculture is largely small-scale and relies on polycultures, which consist of many crops being grown on the same plot with possibilities of symbiotic leguminous relationships providing nitrogen fixation. In addition to intercropping, trees and shrubs (agroforestry) are the anchor perennial species, providing *mycorrhizae* for mobilizing phosphorus and other nutrients, and these trees and shrubs promote soil protection against erosion by wind and water. Also, each of Africa's main staples and about 300 leafy vegetables have perennial cultivars and provide a starting point for the genetic selection and breeding of the best cultivars to incorporate into the traditional tree-and-shrub polyculture in farming households.

Development of Genetically Modified Organisms (GMOs) should aim to tap these special qualities of Africa's native flora and native fauna in the efforts to improve food security and make genetic engineering beneficial to Africa's environment and development. Research will need to be based on meaningful partnerships between users and researchers if it is to be more responsive to local needs. Given the multiplicity of Civil Society Organizations and other public interest groups, there is considerable opportunity for developing such partnerships. Partnerships with the private sector are essential for the sharing of technologies, information and knowledge. A biosafety approach would include taking measures to minimize risks to human and environmental health. This could include:

- Ensure that thorough information is available and that risks are understood and mitigated.
- Products containing GMOs must be clearly labelled and information readily available.
- Clear and fair liability laws and producer responsibilities must be established.
- Genetic and biological material should be managed and contained to high standards.
- Evidence-based GMO risk assessments to assure transparent decision making based on human health and ecological data need to be developed.

Risk assessments should be on a case-by-case basis as results obtained from other countries might not be replicable. Deliberative approaches should be considered. The controversy around risks and opportunities demonstrates the need for effective multilevel assessment procedures that incorporate a precautionary approach as envisaged under the Cartagena Protocol.

This policy and legislative approach needs to be complemented by capacity development. Countries need to have the capacity to identify GMOs and also to evaluate the risks associated with them. Possible mitigation plans should be in place in case undesirable outcomes are experienced. This requires that African countries should establish efficient traceability systems as part of their mitigation measures (UNEP 2006).

The results of genetic modification of plants are usually divided into two categories: those that increase yield and those that increase reliability of performance. Although these modifications can affect the persistence of plants, it will be persistence of domesticated crops because many persistence-related traits have been eliminated through breeding. Plant breeders have a long history of safe field testing and introduction of many genetically modified crops. When problems occur they have been manageable and for the most part confined to the managed ecosystem. Routinely used methods of plant confinement offer a variety of options for limiting both gene transfer by pollen and direct escape of the genetically modified plant. Methods of confinement include biological, chemical, physical, geographical, environmental, and temporal control as well as limitation of the size of the field plot (National Research Council 1989).

The Kyoto protocol provides for a mechanism which enables countries to fulfill their obligation of reduction of greenhouse gasses (e.g. Kadaster International 2008). A farmer can sell emission rights if he/she changes his land use into land use that allows for more carbon storage: reduction of livestock density, removal of wild grazing animals, conversion from cropping to grazing, conversion from conventional to no-till cropping, revegetation (trees, fodder shrubs) and forestry development. To market carbon credits, a title is required. This title for carbon sink is separated from the title of the land ("unbundling property rights"), it also is very suitable for registration in a land registry (Kadaster International 2008).

Agroforestry systems may not lead to significant long-term soil carbon sequestration (Lehman and Gaunt 2004; Harmand et al. 2004), because the main difference in sequestration between an arable system and an agroforestry system lies in the carbon immobilized in the tree biomass (Alegre et al. 2004). However, in Chap. IV.16 a much more positive picture is given.

Conversion of forests to non-forest land use, rapidly releases stored carbon as carbon dioxide impacting the atmosphere and climate for centuries. The conversion of a coastal old-growth forest to a younger plantation forest reduces carbon storage by more than 300 t of carbon per hectare over a 60-year rotation, and total carbon storage is reduced for at least 250 years.

For example the past century's conversion of 5 million hectares of old-growth forests to younger plantations in Oregon and Washington released 1.5–1.8 billion tonnes of carbon to the atmosphere. As a result, conservation of British Columbia's natural ecosystems can have a strong impact on the avoidance of carbon emissions. In comparison, the planting of trees on an unforested site has no net carbon dioxide benefits over the first 10–20 years (Wilson and Hebda 2008).

References

Alegre J, Krishnamurthy L, Callo-Concha D (2004) Carbon sequestration by Amazonian agroforestry systems. Proceedings of the 1st World Congress of Agroforestry – Book of Abstracts, Institute of Food and Agricultural Sciences, University of Florida, Orlando, p 162

Chan AK (2001) Application of basic knowledge on relationship between meteorological factors and sustainable agricultural production and protection of commercial tree crops. Report of the CAgM Working Group on Weather and Climate Related to Agricultural Production. CAgM Report 87, WMO/TD 1079, Geneva, pp 61–80

Commission on Sustainable Development (CSD) (2005) African regional implementation review for the 14th session of the Commission on Sustainable Development (CSD-14). Prepared by UNEP, Nairobi. http://www.uneca.org/csd/CSD4_Report_on_Climate_Change.htm

Ghosh K, Chattopadhyay N, Das HP, Samui RP, Balsubramanian R, Rajavel M (2005) Effect of rainfall variability on coconut and tea over Kerala. In: Nybe EV, Prasada Rao GSLHV (eds) Drought management in plantation crops. Proceedings of the National Workshop, KAU, Thrissur, pp 84–87

Gurusamy A, Natarajan C, Vaithilingam R, Arulraj S (2008) Analysis on seasonal rainfall behaviour and its influence on the productivity of coconut. J Agrometeorol 10:408–410

Harmand JM, Njiti C, Bernhard-Reversat F, Olivier R, Feller C (2004) Changes in below ground carbon stocks during rotation "Tree improved fallow – Crops" in the dry tropics of Cameroon. Proceedings of the 1st World Congress of Agroforestry – Book of Abstracts, Institute of Food and Agricultural Sciences, University of Florida, Orlando, p 182

Kadaster International (2008) Cadastres and climate change. Abroad (Periodical Newsletter of Kadaster International). Special edition of December. http://www.kadaster.nl/pdf/abroad_200812.pdf

Lehman J, Gaunt J (2004) Carbon sequestration in soils under agroforestry. Proceedings of the 1st World Congress of Agroforestry – Book of Abstracts, University of Florida, Institute of Food and Agricultural Sciences, Orlando, p 190

Maracchi G, Sirotenko O, Bindi M (2005) Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. Clim Change 70:117–135

National Research Council (1989) Field testing genetically modified organisms: framework for decisions. Committee on Scientific Evaluation of the Introduction of Genetically Modified Microorganisms and Plants into the Environment. National Academic Press, New York, 184pp. http://www.nap.edu/catalog.php?record_id=1431#toc

Owusu-Manu E (1996) Agroclimatic factors and cocoa production. CAgM Report 67, WMO/TD 747, Geneva, 33pp

Rajagopal V, Naresh Kumar S (2005) Drought management strategies in coconut under different agroclimatic zones. In: Nybe EV, Prasada Rao GSLHV (eds) Drought management in plantation crops. Proceedings of the National Workshop, KAU, Thrissur, pp 35–40

Reed M (2000) A comparative review of agroforestry practices in two forest-adjacent parishes on Mount Elgon, Uganda. Mount Elgon Conservation and Development Project. http://www.see.leeds.ac.uk/misc/elgon/agroforestry.html

Ruark GA, Schoeneberger MM, Nair PKR (2003) Roles for agroforestry in helping to achieve sustainable forest management. UNFF Intersessional Experts Meeting on the Role of Planted Forests in Sustainable Forest Management, New Zealand. http://www.maf.govt.nz/mafnet/unff-planted-forestry-meeting/conference-papers/roles-for agroforestry.htm

Stathers RJ, Rollerson TP, Mitchell SJ (1994) Windthrow handbook for British Columbia forests. Working Paper 940, Ministry of Forests, Victoria, 33pp

UNEP (2006) Africa environment outlook 2. UNEP, Nairobi. http://www.unep.org/dewa/Africa/publications/AEO-2/content/001.htm

Wilson SJ, Hebda RJ (2008) Mitigating and adapting to climate change through the conservation of nature. Land Trust Aliance of British Columbia, Salt Spring Island, 58pp. http://www.landtrustalliance.bc.ca/docs/LTAClimateChangeWebSingleP.pdf

Zhao Y, Wang C, Wang S, Tibig LV (2005) Impacts of present and future climate variability on agriculture and forestry in the humid and sub-humid tropics. Clim Change 70:73–116

III.5.5.(δ) Designing and Communicating Improvements in Farm Applications of Risk Information Products in Agroforestry

Kees Stigter

The concept of "optimization" of the production of various products and services, with minimum risk, from a unit of land, as opposed to "maximization" of a single commodity in monocultural production systems, may be considered new in agroforestry since about 20 years (Lundgren 1897; Nair 1989). For the time being, methods that are low-cost and affordable by farmers must be found to redress the degradation of the natural resources base, particularly soils and forests, while farmers and rural communities need institutional mechanisms that can begin to place pressure and build leverage so that their voices and concerns can be acted upon and implemented (Scott 1996).

The most thorough discussion of risk, uncertainty and agroforestry has been given by Senkondo (2000). He argued among others that interrelationship between an agricultural crop and a tree crop on a single piece of land may be supplementary, complementary or competitive. In the former two cases agroforestry is always an attractive option (see also Nair 1993; Boffa 1999). Examples of instances where agroforestry can increase risk are (Senkondo 2000):

- Tree products are mainly sold in an uncertain future, where prices are not known with certainty during the planting period. The long time taken by trees to realize output as compared to annual crops may act as an impediment to adoption;
- A combination of trees and crops may promote diseases and pests. For example, agroforestry technology versus tsetse re-invasion. The question whether experiences with tsetse flies in Tanzania would limit adoption of agroforestry or not is yet to be answered;
- Tree product markets in developing countries are still underdeveloped thus acting as a potential source of risk in agroforestry income.

Because of the above three instances, an agroforestry strategy needs to be based on the bottom line question: "How and to what extent can one prove that

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_85,

agroforestry systems (including those resulting from current research) enhance the farmer's capability and options to improve or reduce risk and uncertainty in his/her production system?" If we can show that an agroforestry system does reduce risk, it will have great economic value to agriculture (Senkondo 2000). This includes risks from weather and climate.

Senkondo (2000) drew among others the following conclusions relevant for our subject here:

- Farmers' actual choices of cropping systems are generally consistent to their risk attitude, risk perception and preference ranking of cropping systems;
- Risk aversion emanating with farmers in Tanzania is more or less similar to that of farmers from other parts of the world;
- Farmers use agroforestry as part of their coping strategies with risk, and the combination of trees (timber/fuelwood combination) + mixed crops had a high preference even when perceived as moderately risky (see also Sect. III.5.5.(ε) and several sections of Chap. III.3).

Risk information products as exemplified above can be improved for farm applications by taking such results and approaches into account. They should always be applied in the context of farmer preparedness strategies (Box III.5.23). It is important to consider different time frames in risk analyses, to simultaneously consider chances for improvements of infrastructure such as roads, and socioeconomic factors such as extension and land and tree tenure (Senkondo 2000).

Box III.5.23

Rathore and Stigter (2007) recommended that preparedness strategies are taken serious because local, federal and international support can be better absorbed and used when more challenges to coping strategies are met within the local possibilities of communities, families and individuals. We reported in Sect. III.3.5.(δ) that Olufayo et al. (1998) concluded that third world scientists should concentrate on problems that have jointly been identified with local farmers. The same of course applies to western scientists working in the third world (see for example Chap. IV.9). Olufayo et al. (1998) also recommended that participatory on-farm validation of new approaches and technologies that take traditional and more recent local expertise into account should particularly be undertaken more frequently.

An example of this in agroforestry was given by Roothaert (2000). He studied indigenous and naturalized fodder trees and fodder shrubs (IFTSs) in central Kenya. It appeared that farmers had specific knowledge about pests which affected IFTSs. Acknowledging that these pests occur is important for the final selection of IFTSs. He indicates that *Trema orientalis* is a clear example of a tree which has almost all the desired characterisitics of an ideal fodder tree, apart from the fact that its leaves are badly eaten by caterpillars during the time when it is needed most as livestock feed. This local knowledge means that its adoption might be hindered.

Other knowledge with important implications for IFTS is toxicity. Two *Acacia* species were associated with toxicity by farmers and did therefore not rank high in preference. *Lantana camara* remains a controversial species since it was sometimes mentioned as causing digestive problems and in other parts of the world it causes death of livestock. But in the study area of Roothaert (2000) it ranked high in preference, and adverse effects were hardly mentioned by farmers. Roothaert (2000) also confirms a positive correlation for farming systems with IFTSs between population density and increased production per animal, the way this was earlier suggested for Kenya for production per unit of land (e.g. Tiffen et al. 1994).

References

Boffa J-M (1999) Agroforestry parklands in Sub-Saharan Africa. FAO Conservation Guide 34, Rome, 230pp

Lundgren BO (1987) Institutional aspects of agroforestry research and development. In: Steppler HA, Nair PKR (eds) Agroforestry: a decade of development. ICRAF, Nairobi, 150pp

Nair PKR (1989) Agroforestry systems in the tropics. Kluwer Academic Publishers, Dordrecht, etc, 664pp

Nair PKR (1993) An introduction to agroforestry. Kluwer Academic Publishers, Dordrecht etc, 499pp

Olufayo AA, Stigter CJ, Baldy C (1998) On needs and deeds in agrometeorology in tropical Africa. Agric For Meteorol 92:227–240

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties – regional perspectives: Asia. In: Sivakumar MVK, Motha R (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 53–69

Roothaert RL (2000) The potential of indigenous and naturalized fodder trees and shrubs for intensive use in central Kenya. Doctoral thesis. Department of Agronomy, Wageningen University, Wageningen, 172pp

Scott RB (1996) Land-use transformation in Africa: the role of agroforestry. In: Mugah JO (ed) People and institutional participation in agroforestry for sustainable development. Proceedings of the Conference, KEFRI, Nairobi, pp 7–16

Senkondo EMM (2000) Risk attitude and risk perception in agroforestry decisions: the case of Babati, Tanzania. Mansholt Studies 17, Mansholt Institute, Wageningen University, Wageningen, 213pp

Tiffen M, Mortimore M, Gichuki F (1994) More people, less erosion. Environmental recovery in Kenya. Wiley, New York, 311pp

III.5.5.(ε) Improving Coping Strategies with Weather and Climate Related Risks in Agroforestry Including the Improved Use of Insurance Approaches

Kees Stigter

Tree planting may among others reduce salinity, improve soil fertility, control and prevent erosion, control water logging, reduce the greenhouse effect, reduce catchment eutrophication, possibly check acidification and probably increase local biodiversity (e.g. Prinsley 1993). Woody plants can play a significant role in the transition phase of agrosilvopastoral systems in semi-arid regions from extensive systems to intensified systems. Woody plants provide buffering functions, stabilizing ecosystem dynamics, and allowing effective use of additional nutrient an water inputs, or allowing effective use of these resources where they occur naturally. So far woody plants have been predominantly used for productive purposes. Substantial changes are required to change the focus to protective and supportive functions (Breman and Kessler 1995). See also Stigter and Baldy (1993) and Box III.5.24.

All over the world, there are ample examples of permanent, slow and fast traditional adaptations to seasonal variability for coping strategies and food security. The return of intercropping, sequential cropping and agroforestry to parts of Asia and the Pacific is an example (Stigter 2007). In fact these adaptations may be seen as the oldest examples of response farming. However, there are no expectations of improvement of these traditional "fitting" methods per se under the presently fastly changing conditions. Their blending with more scientific meteorological/climatological approaches into actual services for farmers appears the only way forwards (Stigter 2007).

Tanzania is listed among the thirteen African countries worst affected by climate change impacts and vulnerability, and having the least adaptive capacities (Thornton et al. 2002). Tanzania is home to several traditional agroforestry systems that have been in practice for hundreds of years. Some have been documented: the Chagga homegardens, the related Mara region homegardens and the traditional *Wasukuma* silvopastoral system (WAC 2009). Incorporating agroforestry systems

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_86,

Box III.5.24

For agrosilvicultural systems in Africa, three situations have been described where the integration of woody plants with cropping has a synergistic insurance effect (Breman and Kessler 1995):

- On sandy soils, in the driest parts of sub-humid zones, or at run-on sites in drier situations where nutrients have become the limiting factor for plant production, woody plants oriented as windbreaks improve germination and establishment of crops by reducing the impact of wind. [We now know that this is particularly a protection from hot dry air (Onyewotu et al. 2004).] One condition is that the woody plants can effectively use subsoil groundwater reserves. [An example are the sandy soils in northern Nigeria (Onyewotu et al. 2003a).] For maximum benefits of windbreaks for crop production, selection and management of woody plants should be oriented at minimizing shallow rooting, and maximum protective biomass with low growth rates. [The same Nigerian example applies (Onyewotu et al. 2003b).]
- In the more humid parts of sub-humid zones, where run-off and leaching are significant processes, evenly distributed woody plants can lead to improved nutrient availability for crops. [See also Boffa (1999).] Selection of woody species and management of the woody plants should be oriented at the combination of minimum light reduction and maximum woody plant production. [See also Baldy and Stigter (1997).]
- Woody plants can lead to a prolonged growing season for crops. Most suitable are relatively humid conditions, and the presence of fertile and deep soils.

into national agricultural development programmes offers more affordable and sustainable sources of soil nutrients through deep soil extraction and nitrogen fixation, as we have seen throughout this sub-chapter. The technologies concerned have indeed been proven to increase the resilience of farming systems by improving agricultural productivity and enhancing the productive use of rainfall in drylands. The intensification and diversification functions of agroforestry practices strengthen the socio-economic resilience of rural populations to climate change (WAC 2009). See also Muhwezi-Bonge (2009).

SCC & Vi Agroforestry (2008a) is the first organization to trade certified carbon dioxide from agroforestry/land use in Africa. Farmers are going to get paid for different types of farming activities. The methods will reduce the leakage of carbon dioxide from the earth and accumulate the absorption of carbon dioxide from the air. A new initiative shows that sustainable land use management practices on small-holder farms in Western Kenya will both increase staple food production and generate carbon revenues (SCC & Vi Agroforestry 2008b).

The initiative gives advisory services to farmers about agroforestry and sustainable land use management who are at the same time, if implementing, participating in climate change mitigation and thereby deriving additional revenues for the environmental mitigation service. The practices include agroforestry, conservation agriculture, nutrient management, tillage/residue management, soil and water management, restoration/rehabilitation of degraded lands and livestock management. More households can be reached. This should also be considered a form of insurance in years that the annual crops fail.

References

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publication Co., New Delhi; Science Publication Inc., Enfield, 237pp

Boffa J-M (1999) Agroforestry parklands in Sub-Saharan Africa. FAO Conservation Guide 34, Rome, 230pp

Breman H, Kessler J-J (1995) Woody plants in agro-ecosystems of semi-arid regions (with an emphasis on the Sahelian countries). Springer, Berlin, etc, 340pp

Muhwezi-Bonge G (2009) Tanzania at risk of failing to feed itself. Africa News. Posted Friday 13 March 2009. http://www.africanews.com/site/Tanzania_at_risk_of_failing_to_feed_herself/list_messages/23719

Onyewotu L, Stigter K, Abdullahi Y, Ariyo J (2003a) Shelterbelts and farmers' needs. LEISA Mag Low Ext Input Sust Agric 19(4):28–29

Onyewotu LOZ, Stigter CJ, Abdullahi AM, Ariyo JA, Oladipo EO, Owonubi JJ (2003b) Reclamation of desertified farmlands and consequences for its farmers in semiarid northern Nigeria: a case study of Yambawa rehabilitation scheme. Arid Land Res Manag 17:85–101

Onyewotu LOZ, Stigter CJ, Oladipo EO, Owonubi JJ (2004) Air movement and its consequences around a multiple shelterbelt system under advective conditions in semi-arid northern Nigeria. Theor Appl Climatol 79:255–262

Prinsley RT (ed) (1993) The role of trees in sustainable agriculture. Kluwer, Dordrecht, etc, 186pp

SCC & Vi Agroforestry (2008a) A ground breaking initiative at the United Nations Climate Change Conference in Poznan in Poland this week. A film showing sustainable agriculture land management resulting in both economic development and generation of carbon revenues for small-scale farmers in the Lake Victoria basin. http://www.sccportal.org/Default.aspx?ID=827&M=News&PID=1534&NewsID=1854

SCC & Vi Agroforestry (2008b) Swedish Cooperative Centre and Vi Agroforestry introduces certified carbon from Africa. http://www.sccportal.org/Default.aspx?ID=827&M=News&PID=1534&NewsID=1278

Stigter K (2007) Addressing climate change in agriculture. Opinion and Editorial, 15 October. http://www.thejakartapost.com/yesterdaydetail.asp?fileid=20071015.F04

Stigter CJ, Baldy CM (1993) Manipulation of the microclimate by intercropping: making the best of services rendered. In: Sinoquet H, Cruz P (eds) Ecophysiology of tropical intercropping. INRA, Paris/Guadeloupe, pp 29–44

Thornton PK, Kruska RL, Henninger N, Kristjanson PM, Reid RS, Atieno F, Odero AN, Ndegwa T (2002). Mapping poverty and livestock in the developing world. International Livestock Research Institute, Nairobi. http://www.ilri.org/InfoServ/Webpub/Fulldocs/Mappoverty/media/index.htm

WAC (2009) Agroforestry options for Tanzania. World Agroforestry Centre Policy Brief 03. http://www.worldagroforestry.org/af1/downloads/publications/PDFs/BR09007.PDF

III.6 Applied Agrometeorology of Other Forms of Agricultural Production

III.6.A Animal Husbandry

III.6.A.(i) Problems and Solutions in Coping with Extreme Meteorological Events in Agricultural Production, and Challenges Remaining for the Use of Science to Contribute to Problem Analyses and Designing Valuable Solutions in This Context: Animal Husbandry

Kees Stigter

Integrated qualitative and semi-quantitative information on weather and livestock management, more in general and under severe weather and climatic conditions, was reviewed by CAgM (Box III.6.1).

Box III.6.1

At extremes of weather, animal health and animal production are at stake. Integrated qualitative and semi-quantitative information on weather and livestock management, more in general (e.g. Starr 1988) and under severe weather and climatic conditions (e.g. WMO 1986, 1989) was reviewed by CAgM. Response of farm animals to extremes of the thermal environment must take into account the presence of organisms that are likely to challenge and infect (WMO 1989). Earlier review literature gave attention to housing management (Smith 1972) more than to coping with natural disasters, with the exception of drought (e.g. Dagvadorj 2001a), but next to stresses, also parasites and pathogens were dealt with (e.g. Starr 1988; Furuuchi 1993).

Brereton et al. (1994) considered it as extremely important and urgent for modern agrometeorology to quantitatively evaluate and forecast animal reproduction as related to the productivity of fodder resources and weather conditions, the objectives being to reduce animal mortality in the years with unfavorable weather. Initially separately but later on more integrated with animal production, in later review literature, weather and climate related fluctuating herbage/forage supply and grazing conditions came in (e.g. Brereton and Korte 1997; Babushkin and Lebed 2002; Kleschenko et al. 2004).

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia;
Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_87,

This already included the estimation of climate change impact (Brunetti et al. 1997; Dagvadorj 2001b; MIMH 2004), extending the regional information on this all in the course of time (Lebed et al. 2004). But the impossibility to take extreme meteorological conditions into account in present climate/grass yield relationships was recognized (Danielov et al. 1996; Kleschenko et al. 2004). The most recent WMO review of weather, climate and animal production was written for the third edition of the CAgM Guide to Agricultural Meteorological Practices by Gomes da Silva (2009).

Cotton and Ackerman (2004) have indicated that animals can be resistant in disasters that are annoying, but not frightening, such as blizzards and slow floods. During disasters that stimulate nervous reactions, such as flashflood, wildfire and tornadoes, animal owners may see a behavioral pattern from their livestock that they are both unprepared and unable to handle. In the better organized countries, emergency systems often have predetermined volunteers who are trained, equipped and coordinated to move into disaster areas to deal with livestock evacuation. Often, this includes local stockmen associations, rodeo contractors and animal control professionals. They operate in coordination and under the direction of a disaster team.

Traditionally, livestock producers everywhere have equipment, resources, experience and practice to move livestock under a variety of conditions. Smaller scale mixed farms may lack livestock movement equipment, or enough equipment to handle their livestock population. This often stems from an operational philosophy. Producers expect the need to move large animals between forage sites and then off site to a market on a regular basis. Smaller farms are only concerned about getting the livestock to the premises. Often acquisitions are made gradually and sequentially with limited equipment.

The result can be a bottleneck for evacuation purposes. Animal evacuation from a disaster area must occur in a coordinated manner, preferably under the direction of an incident command team to allow success without impeding handling of the disaster and while protecting public safety (Cotton and Ackerman 2004). The following is from the same source but adapted to more general conditions. What is of greatest importance is understanding of animal reactions and selective preparedness for each disaster.

Flash floods usually occur in areas where the landscape cannot absorb all the water during excessive precipitation events, in steep gradient landscapes, or in zones that have been recently affected by drought or wildfire. Living downstream from a significant precipitation event is a danger zone. Knowing if you are actually downstream may not necessarily be apparent since many flash floods happen in arid areas. Livestock has a natural move away instinct to flash flood waters. They generally seek higher ground if possible.

When purchasing or designing your livestock operation, it is important to allow livestock a way to reach high ground in each pasture. Without access, livestock will fight fences and be at a greater risk of drowning. Livestock will initially panic during flash floods. Floods caused by tropical storms have actually left floating dairy cattle suspended in trees when the waters receded. If you live in large flood regions, it may be useful to invest in a good boat to help manage your livestock under disastrous conditions.

Tornadoes have extreme intensity, wind speeds 2–3 times that of a hurricane, but they have a very short duration. Livestock hear and sense impending tornadoes. Do not cut your safety margin short since tornadoes can veer, change speed and change footprint width very quickly. Hurricanes usually become an issue for livestock when the storm reaches landfall. Hurricanes often generate coastal flooding and are accompanied with high winds and heavy rain. When advance warning is available, livestock can be moved inland prior to the storm's arrival.

Most livestock move away from a blizzard storm onslaught unless they are moving to a habitual source of shelter. Some livestock shelters (canyons, draws and windbreaks) can start out as protection in a snow storm and quickly become "drift over" hazards, so you may need to move livestock to shelter areas that have reduced risk of being buried by the drifting snow.

Livestock will resist being moved from an area with limited protection and usually also resist efforts to move them into the face of a storm. For this reason, plan your management approach as early as possible. Young animals are a special risk since they can get buried in snow more easily and have less physical strength and less resistance to cold exposure. Address the young animals first and the older livestock will often follow from both maternal instinct and herd instinct. Although animals rarely get frantic or panicky during blizzards, they do get determined to avoid the wind, cold and poor footing.

Although the surface speeds of wildfires vary from 5 to 40 miles/h, all wildfires generate smoke, heat and sound. Livestock is very sensitive and responsive to wildfire anywhere within their sensory range. Normal reactions vary from nervousness, to panic, to aggressive and resistive escape attempts. Livestock is often injured or killed by fleeing from a wildfire into fences, barriers and other fire risks. Once the flight syndrome kicks in, it is retained long after the smoke, heat and noise stimuli are removed. Some animal species such as alpacas, llamas and especially horses become virtually unmanageable in the face of oncoming wildfire.

Drought is a silent disaster (along with famine and pestilence) because it has a slow onset period that does not encourage monitoring because of its discomfort. The key elements to managing animals in drought disaster are food, water and shelter. The lack of any of these factors, or a scarcity of one or more, can lead to a slow death for livestock. Animal reaction to drought is slow and vague until at critical health levels. Of all the disaster types, drought has the greatest potential to affect the widest area, often impacting large regions at the same time (Cotton and Ackerman 2004).

As far as greenhouse gases as an agent for climate change and the related extreme events are concerned, cattle emit methane through a digestive process that is unique to ruminant animals called enteric fermentation. The methane is a by-product of feed digestion by animals when carbohydrates are broken down into smaller molecules more easily absorbed by the organism. It is emitted from animal manure when it is stored in anaerobic conditions (liquid manure or semi-liquid manure). Vergé et al. (2007) give detailed regional sources and amounts. Nitrous oxide emissions are produced by ruminant livestock as their manure and urine is deposited on the soil. While more research is needed to better quantify nitrous oxide emissions from livestock production systems and to identify specific options for reducing emissions, efficiency improvements can reduce nitrous oxide emissions.

Emission can be limited by improving feed digestibility. Since methane represents a loss of carbon from the rumen and therefore an unproductive use of dietary energy, scientists have been looking for ways to suppress its production. Many different management practices can improve a livestock operation's production efficiency and reduce greenhouse gas emissions. Some of the most effective practices include (USEPA 2008):

- Improving grazing management.
- Soil testing, followed by the addition of proper amendments and fertilizers.
- Supplementing cattle diets with needed nutrients.
- Developing a preventive herd health program.
- Providing appropriate water sources and protecting water quality.
- Improving genetics and reproductive efficiency.

Filtering methane from barns is another potential mitigation option, while another important approach is to further decrease the amount of feed units necessary to produce one meat or milk unit (Vergé et al. 2007).

Improved livestock management can also reduce atmospheric concentrations of carbon dioxide through the mechanism of soil carbon sequestration on grazing lands. As plants grow, they remove carbon dioxide from the atmosphere. Even though a large portion of the plant material is harvested by grazing cattle, through good management residues accumulate and increase the amount of organic matter in the soil. Some of this organic matter will remain in the soil or plant root system for long periods of time instead of being released back into the atmosphere as carbon dioxide.

More work is still needed to develop methods for quantifying the amount of carbon sequestered on-farm and to identify specific practices that accelerate the rate of sequestration (USEPA 2008). Vergé et al. (2007) give some other regional ideas on improvements (Box III.6.2).

Box III.6.2

Vergé et al. (2007) give some regional ideas on improvements. In India, improved genetic stock of dairy cow fed with supplementary forages (minerals and bypass protein) will help decrease methane emissions. In South America increasing the part of legumes to improve pastures and ranges and extending their production areas can contribute to reduce enteric fermentation by providing cattle with a more digestible feed.

In North and Central America improving livestock management, especially, diet, can contribute to reduce greenhouse gas emissions. Most often stored as a liquid, pig manure is a large source of methane here. Reverting to solid manure storage and handling would help to reduce emissions as well. The separation between livestock and crop production systems is an issue. In mixed systems, crop producers dispose of manure as soil amendment, compared to greater reliance on chemical fertilizers in the present context. Attempts are made to link animal and crop producers, but this practice is not generalized.

In Europe, improvement in animal production, e.g. more milk per animal, contributed to reduce the dairy cow population. Pigs are a major industry in Europe and some attempts are already underway to use liquid manure as feedstock for biogas generation. Extension of this practice will reduce methane production.

References

Babushkin OL, Lebed LV (2002) Validation of information requirements on livestock and pasture production in arid and semi-arid regions. CAgM Report 86, WMO/TD 1134, Geneva, 76pp

Brereton AJ, Danielov SA, Scott D (1994) Agrometeorology of grasslands for middle latitudes. CAgM Report 59. WMO/TD-No. 616, Geneva, 98pp

Brereton AJ, Korte CJ (1997) The definition of agrometeorological information required for pasture and livestock production in temperate regions. CAgM Report 71, WMO/TD 809, Geneva, 51pp

Brunetti A, Ford PB, Kanemasu ET, Labalans WN, Mills PF, Mulder R, Sirotenko OD, Wang F (1997) Weather/climate and sustainable agricultural production and protection. CAgM Report 74, WMO/TD 838, Geneva, 112pp

Cotton S, Ackerman R (2004) Caring for livestock during disaster. Livestock Series Management. http://www.ext.colostate.edu/pubs/livestk/01815.pdf

Dagvadorj D (2001a) Weather and climate related to pasture and livestock production in arid and semi-arid regions. CAgM Report 79, WMO/TD 989, Geneva, 26pp

Dagvadorj D (2001b) Climate change impacts on rangeland and cattle production in Mongolia. Contributions from Members on Operational Applications in Agrometeorology and from Discussants of the Papers Presented at the International Workshop on Agrometeorology in the 21st Century, Needs and Perspectives. CAgM Report 77b, WMO/TD 1029, Geneva, pp 31–34

Danielov SA, Gringof IG, Germogenov MT (1996) Definition of agrometeorological information required for pasture and livestock production in cold climate regions. CAgM Report 69, WMO/TD 751, Geneva, 51pp

Furuuchi S (1993) Weather and animal diseases. Part II in CAgM Report 52, WMO/TD 524, Geneva, 37pp

Gomes da Silva R (2009) Weather and climate and animal production, Chapter 11. Guide to agricultural meteorological practices (GAMP). WMO 134, Geneva. Available at the WMO/CAgM

and INSAM (www.agrometeorology.org) websites. http://www.agrometeorology.org/files-folder/repository/gamp_chap_11.pdf
Kleschenko A, Grom L, Ndiaye M, Stefanski R (2004) The impacts of agrometeorological applications for sustainable management of farming, forestry and livestock systems. CAgM Report 92, WMO/TD 1175, Geneva, 70pp
Lebed LV, Gandega Y, Rijks D (2004) Impact of agrometeorological information on rangeland and pasture ecology and management. CAgM Report 96, WMO/TD 1229, Geneva, 24pp
MIMH (2004) Climate change impacts on animal husbandry in Mongolia. Mongolian Institute of Meteorology and Hydrology, Ulann Baatar, Mongolia. Contributions from Members on Operational Applications in Agrometeorology and from Discussants of the Papers Presented at the International Workshop on Reducing Vulnerability of Agriculture and Forestry to Climate Variability and Climate Change. CAgM Report 94, WMO/TD 1213, WMO, Geneva, pp 36–38
Smith CV (1972) Some environmental problems of livestock housing. Technical Note 122, WMO 325, Geneva, 71pp
Starr JR (1988) Weather, climate and animal performance. Technical Note 190, WMO 684, Geneva, 121pp
USEPA (2008) Ruminant livestock. How can livestock methane emissions be reduced? www.epa.gov/rlep/faq.html
Vergé XPC, De Kimpe C, Desjardins RL (2007) Agricultural production, greenhouse gas emissions and mitigation potential. Agric For Meteorol 142:255–269
WMO (1986) Land use and agrosystem management under severe climatic conditions. Technical Note 184, WMO 633, Geneva, 161pp
WMO (1989) Animal health and production at extremes of weather. Technical Note 191, WMO 685, Geneva, 181pp

III.6.A.(ii) Selection of Actual Preparedness Strategies for Dealing with Climate, as Adopted in Animal Husbandry

John Gaughan

Three tenants of Article 2 of the UN Framework Convention on Climate Change (UNFCC), by which, for their preparedness, decision makers are to assess progress in stabilizing greenhouse gas concentrations to levels which will prevent dangerous anthropogenic interference with climate change are: (i) allow ecosystems to adapt naturally to climate change, (ii) ensure that food production is not threatened and (iii) enable economic development to proceed in a sustainable manner (Smith et al. 2009).

The impact of climate change on livestock production is complex and is most likely going to be a result of multiple stressors. Preparedness is essential (Box III.6.3). The solution is also complex and multi-factorial (Box III.6.4). The impact is likely to be greater in dry regions, megadeltas and islands (Smit and Yunlong 1996). Climate has direct and indirect effects on livestock production.

Box III.6.3

Climate change is seen as a major threat to the viability of livestock production systems in many parts of the world. Studies have suggested that severe economic and production losses are likely if management systems are not modified to prepare for changing climatic conditions. Farmers need to be in a position to adapt quickly to climatic change, they need to be prepared for change (ILRI 2006). They need to be informed and trained early – changing management after the system has failed often results in lack of success, especially where there are limited financial reserves.

Farmers in more flexible and manageable livestock systems need to be proactive environmental caretakers in order to reduce the risks associated with climate change (Gaughan et al. 2009). If they are not, then it is highly likely that famine will result in many areas of the world (Parry et al. 2004). Regions

J. Gaughan (✉)
The University of Queensland, Gatton, QLD, Australia
e-mail: j.gaughan@uq.edu.au

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_88,

which have little adaptive capacity, usually due to a weak economic position, are more vulnerable to climate change (Smith et al. 2009). Planning and implementation of preparedness strategies to reduce the negative impacts of climate change must start now. Adaptation is not a simple process – planning for success is essential.

Box III.6.4

The following example illustrates the complexity of finding a solution to climate change. Seo and Mendelsohn (2007) undertook an analysis on the impact of climate change on animal husbandry in Africa. Their study was based on a survey undertaken by the World Bank and the Global Environment Facility (GEF) project. This survey involved over 9,000 farms across 11 countries. Two models were tested. The first examined net revenues per farm based on climatic and other control variables, and the second examined the value of animals owned per farm, and the net revenue per value of owned animal. They reported that although the first model indicates that the net revenue from livestock production of large farms will fall as temperatures rise, small farms are not affected. The second model suggests that the larger farms will reduce the number of animals and net return per animal will decrease. The number of animals on small farms will not be affected, and there will be an increase in net revenue per animal. So, large farms are more susceptible to climate change than smaller farms. Why does this dichotomy exist? Basically because of the ability to adapt.

Seo and Mendelsohn (2007) report that whereas large farms rely on cattle that are not suited to hot conditions, small farms can easily change to more heat tolerant species such as goats. Their models suggest that an increase in rainfall would reduce net revenue from livestock for both large and small farms. This would come about due to a reduction in animals and a fall in net returns per animals. Again the story is complex. More rain means more productivity of grasslands but also increases tree growth, so there is a loss of grazing land. In addition, warm wet conditions increase the likelihood of animal diseases. However, increasing rainfall allows farmers to shift from livestock to crops. Furthermore, as rainfall decreases, livestock net revenue increases for both large and small farmers. They conclude that livestock provides an important agricultural adaptation if there are reductions in rainfall. There is no simple solution to a complex problem. The importance of livestock as a potential buffer against climate change should not be ignored.

The direct effects of climate include factors such as the impact of heat load on reproduction, and survivability. Indirect effects include influences on the availability of affordable feed grain, changes in pasture and forage crop production, changes in the quality of feed resources, and changes in the distribution of pests and diseases (Rotter and Van de Geijn 1999; Seo and Mendelsohn 2007). Without preparedness the latter two in particular could have devastating effects.

An increasing demand for meat in developing countries has seen an increase in intensification of animal industries, and a move to cross bred animals which have higher levels of productivity than many indigenous breeds (Tisdell 2003; Hoffmann and Beate 2006). High production animals are in general less able to cope with environmental stress. Therefore reductions in performance may be greater in those regions where productivity has been improved via better genetics, nutrition and management. Preparedness for climate change has to a large extent decreased in these regions.

Preparedness strategies which may be used to reduce the impact of climate change on livestock production include a redistribution of livestock within a region, changes in pasture management, changes in feeding techniques (e.g. less reliance on feed grains), breeding new crop and pasture plant varieties, changing the breeds used (e.g. selection of heat or parasite tolerant animals); this may mean a return to the use of indigenous breeds over imported high production breeds, or even a complete change in the species used (e.g. changing from cattle to goats).

All of these options have human, land and economic resource implications. If change for better preparedness is to be successfully implemented, there will be a need for sufficient financial support, otherwise conflicts over limiting resources could arise, as has for example already been seen in the Sudan and Nigeria.

Spreading the risk associated with climate change by diversification may also be a useful preparedness strategy. Farmers may need to look at mixed livestock operations where for example they may need to keep both cattle and goats. A key factor in livestock production is reproduction or herd/flock fertility. Increasing ambient temperature will impact on the reproductive performance of both males and females.

Data clearly show a significant link between climatic conditions and fertility in dairy cows (De Rensis and Scaramuzzi 2003; Morton et al. 2007) and for beef cows (Amundson et al. 2006). It is likely that other grazing species will also be affected. Although the impact is greater on high production animals, all breeding animals will be negatively affected by exposure to high temperatures. Furthermore high production animals are more likely to be impacted by shortfalls in nutrition.

The quality of products from animals is often overlooked in the climate change debate. Heat stress reduces the protein and fat content of cows milk, in addition to reductions in milk output. Meat from cattle, sheep, goats and chickens is also affected by heat stress. The impact of this reduces shelf life, and eating quality, and again there is an overall reduction in output (kg).

Housing animals is another strategy that can be used. Intensification of livestock production has the potential to negate some of the impacts of climate change. The use of housing has allowed the expansion of a dairy industry based on European genetics into regions such as Brazil and Saudi Arabia, areas that would otherwise be unsuitable for these animals (Darwin et al. 1995). However there can be substantial financial costs in connection with construction, associated infrastructure, maintenance and daily running practices. Therefore there is a need to investigate cheaper housing options which will help to alleviate the impact of climate change on livestock. For example simple shade structures can reduce the heat load on grazing animals by as much as 80%.

Climate change will not only result in an increase in mean global temperature, it is also to bring about changes in regional rainfall patterns, and an increase in the intensity of droughts, cyclones and floods (Smith et al. 2009). There will be a need in better preparedness to assess management strategies in terms of water availability. Will for example current water sources, dams, bores, wells or rivers hold sufficient water for livestock needs in the future? Before building any new water infrastructure, predicted changes in rainfall need to be considered.

The risk of increased flooding and rising sea levels may necessitate the preparative building of levies to protect grazing and cropping land (as well as villages, towns and cities). More intense cyclones and the risk of tidal surges, along with rising sea levels necessitate the preparatory use of sea walls to protect livestock, grazing land and crop production.

Fundamental changes in livestock production are at times (and possibly much of the time) in conflict with cultural, social and political requirements. The best preparedness for change is aiming at change driven by the end users. The key to successful adaptation of farmers to climate change is, in addition to education and training, the use of local knowledge on what works and what does not. But also here preparedness demands new choices.

References

Amundson JL, Mader TL, Rasby RJ, Hu QS (2006) Environmental effects on pregnancy rate in beef cattle. J Anim Sci 84:3415–3420

Darwin R, Tsigas M, Lewandrowski J, Raneses A (1995) World agriculture and climate change – economic adaptations. Agricultural Economic Report 703, ERS-NASS, Herndon, 100pp

De Rensis F, Scaramuzzi RJ (2003) Heat stress and seasonal effects on reproduction in the dairy cow – a review. Theriogenology 60:1139–1151

Gaughan J, Lacetera N, Valtorta SE, Khalifa HH, Hahn L, Mader T (2009) Response of domestic animals to climate challenges. In: Ebi KL, Burton I, McGregor GR (eds) Biometeorology for adaptation to climate variability and change. Springer, Heidelberg, etc, pp 131–170

Hoffmann I, Beate S (2006) Animal genetic resources – time to worry? Livestock Report 2006, FAO, Rome, pp 57–76

ILRI (International Livestock Research Institute) (2006) Climate change research by ILRI informs Stern review on the economics of climate change. http://www.ilri.org/ILRIPubaware/

Morton JM, Tranter WP, Mayer DG, Jonsson NN (2007) Effects of environmental heat on conception rates in lactating dairy cows: critical periods of exposure. J Dairy Sci 90:2271–2278

Parry ML, Rosenzweig C, Iglesias A, Livermore M, Fischer G (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Glob Environ Chang 14:53–57

Rötter R, Van de Geijn SC (1999) Climate change effects on plant growth, crop yield and livestock. Clim Change 43:651–681

Seo SN, Mendelsohn R (2007) Climate change impacts on animal husbandry in Africa: a Ricardian analysis. World Bank Research Paper 4261. http://ssrn.com/abstract=996167

Smit B, Yunlong C (1996) Climate change and agriculture in China. Glob Environ Chang 6:205–214

Smith JB, Schneider SH, Oppenheimer M, Yohe GW, Hare W, Mastrandrea MD, Patwardhan A, Burton I, Corfee-Morlot J, Magadza CHD, Füssel H-M, Pittock AB, Rahman A, Suarez A, van Ypersele J-P (2009) Assessing dangerous climate change through an update of the Intergovernmental Panel on Climate Change (IPCC) "reasons for concern". PNAS 106:4133–4137

Tisdell C (2003) Socioeconomic causes of loss of animal genetic diversity: analysis and assessment. Ecol Econ 45:365–377

III.6.A.(iii) Designing and Selecting Efficient Early Warning Strategies and Increasing Their Efficiencies for Animal Husbandry

John Gaughan and LeRoy Hahn

Thermal indices such as the Temperature Humidity Index (THI) (Thom 1959) are useful tools for the management of domestic animals during periods of hot weather. The usefulness of a climate index is limited, however, if it is not in some way related to an animal response. The biological response of animals to prevailing weather conditions has been studied and quantified within the context of weather conditions (e.g. Berry et al. 1964; Hahn and McQuigg 1970a; Hahn 1976; Baccari 2001; Eigenberg et al. 2008; Gaughan et al. 2008).

The results from theses studies are based on observations of a selected performance criterion (such as growth rate, milk production, reproduction or egg production). These are made concurrently with measures of the thermal environment as input for the selected thermal index (whether it be the THI or others, see below), and an empirical relationship is developed. This places more emphasis on the biological consequences associated with the index values. Additionally, if the same thermal index is selected for the response functions of multiple performance criteria and species, there is opportunity for broader application of the index climatology (Hahn et al. 2009).

The THI has been extensively applied for moderate to hot conditions using this approach, even with recognized limitations in that it does not take airspeed and radiation heat load into account. However, temperature and humidity do have a major influence on the heat exchange between an animal and its environment and hence in many cases adequately represent the thermal impact on livestock (St-Pierre et al. 2003; Brown-Brandl et al. 2005). Even with some limitations, the THI has become a de facto standard for classifying thermal environments and selection of management practices to alleviate the impact during periods of hot weather (Hahn et al. 2009).

The THI has been used to predict animal responses (milk production, growth rate and reproduction) to climatic conditions. For dairy cows see Ingraham et al. (1974), Du Preez et al. (1990), Roseler et al. (1997), Mayer et al. (1999), Jonsson et al. (1997) and Morton et al. (2007). For sheep and goats: Khalifa et al. (2005).

J. Gaughan (✉)
The University of Queensland, Gatton, QLD, Australia
e-mail: j.gaughan@uq.edu.au

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_89,

For beef cattle: Amundson et al. (2006); Mader et al. (2006). For poultry: Yalchin et al. (2001). For turkeys: Brown-Brandl et al. (1997).

The THI has also been used to model the impact of future climate predictions on animal production, health and welfare. Initially, it was used to estimate milk production decline during summer months for shaded dairy cows in various US locations, based on climatological analyses of the THI (Hahn and Osburn 1969; Hahn and McQuigg 1970b). These estimated production declines compared favorably (within 4–15%) with actual declines measured during summertime trials in four US locations (Hahn 1969). Other climatic analyses of the THI have since been completed for other locations within the US (e.g. Huhnke et al. 2001) and for several dairy production areas of the world, where summer conditions cause reductions in production and reproduction, such as in Argentina (Valtorta et al. 1998; De la Casa and Ravelo 2003); Australia (Davison et al. 1996; Morton et al. 2007), Brazil (Da Silva 2000), and South Africa (Du Preez et al. 1990).

The predicted animal responses have subsequently been used to estimate the benefits of environmental modification practices such as the provision of shade, evaporative cooling (water application and use of fans), housing designs to maximize natural ventilation and nutritional management. The THI has also been used to predict the effect of climate change on beef cattle production in Australia (Howden and Turnpenny 1997).

Modifications to the THI have been proposed to overcome shortcomings related to airflow and radiation heat loads. An example is the Black-Globe Temperature-Humidity Index (BGHI; Buffington et al. 1981), which uses black-globe temperature instead of dry-bulb temperature in the THI equation. Mader and Davis (2002) and Eigenberg et al. (2005) have proposed corrections to the THI for use with feedlot cattle, based on incorporation of wind speed and solar radiation.

Baeta et al. (1987) developed an Equivalent Temperature Index (ETI) for dairy cows in above-thermoneutral conditions, which combined the effects of air temperature and humidity with airspeed to evaluate the impacts on heat dissipation and milk production. A somewhat similar approach was used to derive an Apparent Equivalent Temperature (AET) from air temperature and vapor pressure to develop “thermal comfort zones” for transport of broiler chickens (Mitchell et al. 2001). A thermal discomfort index for sheep and goats was developed by Khalifa et al. (2005) based on animal responses (rectal temperature, respiration rate and metabolic rate). The THI was used as the base thermal index and THI thresholds developed to classify conditions in terms of stress.

Gaughan et al. (2008) have developed a Heat Load Index (HLI) based on cattle response (respiration rate and body temperature) as a guide to the management of feedlot cattle during hot weather (Box III.6.5). The HLI is based on humidity, wind speed, and black globe temperature. Stress thresholds were developed based on cattle responses to climatic conditions. Eigenberg et al. (2005) developed a linear regression-based estimator for respiration rate (ERR) of feedlot cattle at temperature levels above 25 °C, using input parameters of dry bulb temperature, relative humidity, wind speed and solar radiation. Both of these models are based on animal responses to prevailing climatic conditions. A number of short term heat stress forecast sites are available (Box III.6.6).

Box III.6.5

A Heat Load Index (HLI) has been developed for feedlot cattle (Gaughan et al. 2008). In association with the HLI, a risk assessment program was developed and can be accessed via the web (www.katestone.com.au/mla) or via a PC. The risk assessment program considers a number of factors including location (historic weather), genotype (% *Bos taurus* and *Bos indicus*, coat color, body condition and health status), management factors (access to shade, area of shade available and temperature of drinking water), heat load mitigation (access to additional water troughs, nutritional management – to reduce metabolic heat, and manure management – cleaning of pens). From these data the risk of heat stress can be determined. Stress threshold, i.e. the HLI at which there are physiological changes associated with heat stress, have been developed for various genotypes (Table III.6.1). These can be increased or reduced depending on the health of the animal and management strategies employed to alleviate heat load.

Table III.6.1. The HLI thresholds for various genotypes

Genotype	Threshold
Bos taurus (British) (100%) (shade)	91
Bos taurus (British) (100%) (no shade)	86
Bos taurus (European) (100%)	89
Bos taurus (75%) × *Bos indicus* (25%)	90
Bos taurus (50%) × *Bos indicus* (50%)	93
Bos taurus (25%) × *Bos indicus* (75%)	94
Bos indicus (100%)	96

Adapted from Gaughan et al. (2008).

Box III.6.6

A number of short term heat stress forecast sites are available in Australia for beef (www.katestone.com.au/mla) (based on the Heat Load Index (HLI)) (Gaughan et al. 2008) and for dairy cattle (www.coolcows.com.au) (based on Temperature Humidity Index (THI)); in New Zealand a service is available for dairy cattle (www.metservice.co.nz/data/hsigraph); in the USA a forecast service for beef cattle is available at (www.ars.usda.gov/Main/docs.htm?docid=17130) (based on Estimator for Respiration Rate (ERR)) (Eigenberg et al. 2008). Other forecast sites include the Oklahoma Livestock Temperature Humidity Index Map (http://agweather.mesonet.ou.edu/models/cattle/default.html (based on THI) and the National Heat Stress Map (http://wwwagwx.

ca.uky.edu/mrf_lsi.htm) (based on THI) (Eigenberg et al. 2008). These sites also provide hot weather warnings for livestock. A number of THI threshold levels are also provided for cattle, pigs, poultry and turkeys at the site (http://www3.abe.iastate.edu/livestock/heat_stress.asp).

The majority of the sites provide a 1–5 day forecast of weather conditions based on official government weather predictions. The predictions are updated at least every 24 h, although there is probably a need for more frequent updates during periods of extreme climatic stress. The accuracy of the predictions is generally sound out to 3 days but is generally of limited value past that. Hence the need for daily updates. In addition government weather bureaus provide 5–7 day forecasts (some via a subscription) which can be used to assess likely impacts on animals – however they lack the animal focus of the models presented above. Private weather service providers (and some government providers) also produce weather advisories to subscribers for a fee. It is likely that other services are available elsewhere.

Longer term models based on sea surface and sub-surface temperatures are used to predict future weather conditions. Regional forecasts based on these and other factors are available via the web. Sea surface temperatures are also being used to predict climate changes some 5–10 years into the future (Keenlyside et al. 2008). Although not specifically animal focused, they do provide current climate outlooks for animal and agricultural production in various regions of Africa and Asia. Longer term predictions, especially if they can be linked to animal performance, may prove to be useful in determining where limited resources should be focused in an effort to ensure the sustainability of animal production in the long-term. Longer term predictions, months or years into the future, are suitable for planning and undertaking risk assessment, but do little to rectify problems faced during heat waves.

The primary limitation in the design and implementation of an efficient early warning system is the dissemination of weather predictions to those that need the information. Furthermore, regional and local conditions can vary substantially from predictions or actual weather data collected at official weather stations. A lack of weather stations in many areas further erodes the confidence in any early warning system, especially at a regional basis.

It is important that there is an understanding of how the biology of the animals will be affected by climatic conditions (and future changes). This will allow planning in terms of environmental modification (e.g. shade structures), resource allocation (e.g. water) and the species.

References

Amundson JL, Mader TL, Rasby RJ, Hu QS (2006) Environmental effects on pregnancy rate in beef cattle. J Anim Sci 84:3415–3420

Baccari Jr. F (2001) Manejo ambiental da vacaleiteira em climas quentes. [Environmental management of dairy cows in hot climates] Editora da Universidade Estadual de Londrina, Londrina, 142pp

Baeta FC, Meador NF, Shanklin MD, Johnson HD (1987) Equivalent temperature index at temperatures above the thermoneutral for lactating dairy cows. Paper 87–4015, ASAE, St. Joseph, 6pp

Berry IL, Shanklin MD, Johnson HD (1964) Dairy shelter design based on milk production decline as affected by temperature and humidity. Trans ASAE 7:329–331

Brown-Brandl TM, Beck MM, Schulte DD, Parkhurst AM, DeShazer JA (1997) Temperature-humidity index for growing tom turkeys. Trans ASAE 49:203–209

Brown-Brandl TM, Eigenberg RA, Nienaber JA (2005) Heat stress risk factors for feedlot cattle. Proceedings of the 7th International Livestock Environment Symposium, ASAE, St. Joseph, pp 559–565

Buffington DE, Collazo-Arocho A, Canton GH, Pitt D, Thatcher WW, Collier RJ (1981) Black globe-humidity index (BGHI) as a comfort equation for dairy cows. Trans ASAE 24:711–714

Davison T, McGowan M, Mayer D, Young B, Jonsson N, Hall A, Matschoss A, Goodwin P, Gaughan J, Lake M (1996) Managing hot cows in Australia. QDPI, Brisbane, 58pp

Da Silva RG (2000) Introducao a bioclimatologia animal. [Introduction to animal bioclimatology.] Nobel, Sao Paulo, 286pp

De la Casa A, Ravelo AC (2003) Assessing temperature and humidity conditions for dairy cattle in Córdoba, Argentina. Int J Biomet 48:6–9

Du Preez JH, Giesecke WH, Hattingh PJ (1990) Heat stress in dairy cattle and other livestock under southern African conditions. I. Temperature-Humidity Index mean values during the four main seasons. Onderstepoort J Vet Res 57:77–87

Eigenberg RA, Brown-Brandl TM, Nienaber JA, Hahn GL (2005) Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle. Part 2: Predictive relationships. Biosyst Eng 91:111–118

Eigenberg RA, Brown-Brandl TM, Nienaber JA (2008) Development of a graphical web-based heat stress forecast for feedlot cattle. Paper No. 083887, ADSABE, St. Joseph, 6pp

Gaughan JB, Mader TL, Holt SM, Lisle A (2008) A new heat load index for feedlot cattle. J Anim Sci 86:226–234

Hahn GL (1969) Predicted vs. measured production differences using summer air conditioning for lactating dairy cows. J Dairy Sci 52:800–802

Hahn GL (1976) Rational environmental planning for efficient livestock production. Biometeorology 6(Part II):106–114

Hahn GL, Osburn DD (1969) Feasibility of summer environmental control for dairy cattle based on expected production losses. Trans ASAE 12:448–451

Hahn L, McQuigg JD (1970a) Expected production losses for lactating Holstein dairy cows as a basis for rational planning of shelters. Int J Farm Bldgs Res 4:2–8

Hahn L, McQuigg JD (1970b) Evaluation of climatological records for rational planning of livestock shelters. Agric Meteorol 7:131–141

Hahn GL, Gaughan JB, Mader TL, Eigenberg RA (2009) Thermal indices and their applications for livestock environments. In: Thermal Environment and Livestock Energetics. ASABE, St. Joseph, pp 113–130

Howden SM, Turnpenny J (1997) Modelling heat stress and water loss of beef cattle in subtropical Queensland under current climates and climate change. In: McDonald DA, McAleer M (eds) Modsim '97 International Congress on Modelling and Simulation Proceedings, 8–11 December, University of Tasmania, Hobart. MSSA, Canberra, pp 1103–1108

Huhnke RL, McCowan LC, Meraz GM, Harp SL, Payton ME (2001) Determining the frequency and duration of elevated Temperature-Humidity Index. Technical Report 01-4111, ASAE, St. Joseph, 12pp

Ingraham RH, Gillette DD, Wagner WD (1974) Relationship of temperature and humidity to conception rate of Holstein cows in subtropical climate. J Dairy Sci 57:476–481

Jonsson NN, McGowan MR, McGuigan K, Davison TM, Hussain AM, Kafi M, Matschoss A (1997) Relationships among calving season, heat load, energy balance and postpartum ovulation of dairy cows in a subtropical environment. Anim Reprod Sci 47:315–326

Keenlyside NS, Lafit M, Jungclaus J, Kornblueh L, Roeckner E (2008) Advancing decadal-scale climate prediction in the North Atlantic sector. Nature 453:8488

Khalifa HH, Shalaby T, Abdel-Khalek TMM (2005) An approach to develop a biometeorological thermal discomfort index for sheep and goats under Egyptian conditions. Proceedings of the 17th International Congress of Biometeorology, International Society of Biometeorology, Garmisch-Partenkirchen, pp 118–122

Mader TL, Davis MS (2002) Wind speed and solar radiation correction for the Temperature-Humidity Index. Proceedings of the 16th Congress ISB./15th AMS Conference on Biometeorology and Aerobiology, Boston, pp 154–157

Mader TL, Davis MS, Brown-Brandl T (2006) Environmental factors influencing heat stress in feedlot cattle. J Anim Sci 84:712–719

Mayer DG, Davison TM, McGowan MR, Young BA, Matschoss AL, Hall AB, Goodwin PJ, Jonsson NN, Gaughan JB (1999) Extent and economic effect of heat loads on dairy cattle production in Australia. Aust Vet J 77:804–808

Mitchell MA, Kettlewell PJ, Hunter RR, Carlisle AJ (2001) Physiological stress response modeling applications to the broiler transport thermal environment. Proceedings of the 6th International Livestock Environment Symposium. ASAE, St. Joseph, pp 550–555

Morton JM, Tranter WP, Mayer DG, Jonsson NN (2007) Effects of environmental heat on conception rates in lactating dairy cows: critical periods of exposure. J Dairy Sci 90:2271–2278

Roseler DK, Fox DG, Pell AN, Chase LE (1997) Evaluation of alternative equations for prediction of intake in Holstein dairy cows. J Dairy Sci 80:864–877

St-Pierre NR, Cobanov B, Schnitkey G (2003) Economic losses from heat stress by US livestock industries. J Dairy Sci 86(E. Suppl):E52–E77

Thom EC (1959) The Discomfort Index. Weatherwise 12:57–60

Valtorta S, Leva P, Castro H, Gallardo M, Maciel M, Guglielmone A, Anziani O (1998) Produccion de lecha en verano. [Milk production in summer.] Universidad Nacional del Litoral, Santa Fe, 18pp

Yalchin S, Ozkan S, Turkmut L, Siegel PB (2001) Responses to heat stress in commercial and local broiler stocks. 1. Performance traits. Br J Nutr 42:149–152

III.6.A.(iv) More Efficient Use of Inputs in Animal Husbandry

John Gaughan, Silvia Valtorta, and Nicola Lacetera

Livestock production accounts for approximately 70% of all agricultural land (Steinfeld et al. 2006). Approximately 3.5 billion hectares are grazed compared to 1.2–1.5 billion hectares under cropping (Howden et al. 2007). Climate change is likely to be a major threat to the viability and sustainability of animal (beef and dairy cattle, goats, sheep, chickens, ducks, poultry etc) production systems in many regions of the world, and could lead to regional famines.

These changes will have direct impacts on animal performance via growth and reproduction, and indirect pressure in terms of limitations in water and feed resources, while there is expected to be an increased disease risk and parasite risk (Hahn 1999; Chase et al. 2004). The economic impact of climate change in relation to animal production has been considered in several studies and reviews (Adams et al. 1990; Frank et al. 2001; Galvin et al. 2001; Reilly et al. 2003; St-Pierre et al. 2003; Thornton et al. 2007). Most predict severe economic losses if current management and support systems are not modified to reflect the shift in climatic conditions. The losses in developing countries are expected to be extreme.

Cattle raising, for example, has a significant role in food production in many developed and lesser developed countries. In 2004, it was estimated that there were more than 1.2 billion cattle in the world. Over 980 million of these were located in developing countries (Groenewold 2004 cited by Hoffmann and Beate 2006). Over the last 50 years the bulk of world production has been obtained from high output breeds which have largely originated in the temperate regions of North America and Europe (FAO 2008). Some additional aspects are in Box III.6.7.

Box III.6.7

An increasing demand for meat in developing countries has led to an increase in the intensification and size of livestock holdings. This is especially evident

J. Gaughan (✉)
The University of Queensland, Gatton, QLD, Australia
e-mail: j.gaughan@uq.edu.au

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_90,

in poultry and pig production but there is also intensification in cattle and sheep production. Many farmers have also undertaken crossbreeding indigenous breeds with European breeds as a way of increasing animal performance. Crossbred animals at least potentially have higher levels of productivity than many of the pure indigenous breeds (Tisdell 2003; Hoffmann and Beate 2006). However, this could be offset by the higher maintenance cost of these animals. Furthermore, the crossbred animals are often more susceptible to environmental stressors. Heat tolerance is considered to be one of the most important adaptive aspects for cattle in many regions (McManus et al. 2009). A lack of thermally-tolerant breeds of cattle is already a major constraint on production in Africa (Voh et al. 2004). (Adapted from Gaughan et al. 2010a; 2010b)

The importance of livestock in the alleviation of poverty and its role in providing food security is well accepted. Livestock are vulnerable to climate change, especially where there is a lack of planning. Animal production within a region is not always well understood by those outside the region – this includes government planners and aid agencies. Before efficiencies in animal production systems can be obtained there is a need to know the inputs that go into a system, and to understand the interactions of the various inputs with the system.

What are the inputs that need to be considered? These include:

(i) People – The most important component for improving the efficiency of inputs in animal husbandry are the people who manage the animals. New commitments in education and training are needed to ensure that farmers will have the necessary skills and knowledge to adapt. There needs to be community involvement. The knowledge that the farmers already have in dealing with climate variation should be used, so this will give community ownership to the integration of the traditional and new management practices. The latter must suit local conditions and be financially and environmentally sustainable.

(ii) Animals – There is a need to identify the major production traits required to understand the effect of the environment on animal performance. Efficient use of genetics can only be achieved if animals are bred to suit the environment (see Box III.6.8), and not by modifying the environment to suit the genetics. There is therefore an urgent need to identify genotypes that will suit the future climatic conditions, especially within species that have longer generation intervals and fewer offspring such as cattle.

Box III.6.8

The following extract looks at case studies in FAO (2001). Six conclusions were drawn from case studies and these are presented.

"In South Africa, European colonization and the subsequent acceptance of the colonial farmer as a role model led to the introduction of exotic breeds that eventually diluted and depleted the original gene pool of indigenous livestock. The colonists often regarded the cattle owned by the Nguni people as inferior, as they appeared to perform poorly, and were less uniform in color and color patterns, which gave the breed the appearance of an indiscriminate mixture of breeds. This perception of inferiority was adopted by the Nguni people who viewed the high input, highly productive exotic breeds as superior to their own, and adopted the colonists' farming practices as their model. The fact that the Nguni cattle were able to survive with minimal care was of secondary importance to commercial farmers, as supplementary feeding and stock remedies were relatively inexpensive. It was only recently that scientific evidence showed that Nguni cattle performed well under the prevailing low-input management practices of communal systems whilst the exotics performed poorly. The Nguni cattle breed is now seen as appropriate to the management style and needs of the emerging farmer, who requires a relatively low maintenance and relatively high output animal."

The conclusions presented are:

- Government policies may have unintended consequences and reduce sustainability of animal genetic improvement efforts if they are not carefully designed to consider genotype x environment interactions and farmers' capabilities to manage them.
- A broad participatory ecosystems approach in designing animal genetic resources development programs is advisable to strengthen production systems, e.g. in terms of efficient nutrient cycling and energy use in the crop/animal interaction on-farm.
- Animal resources development strategies will have the greatest impact when there is community involvement integrating traditional practices, knowledge, and innovations with modern livestock breeding and management practices.
- In animal resource development efforts in which primarily small animals are the target, gender-sensitive methodology is required if genuine livelihood improvements are to be achieved, given that these species are predominantly associated with women farmers.
- As small animals in traditional farming are not only strongly associated with women farmers but also with the poor and often with both at the same time, gender- and poverty-sensitive approaches are essential for enhancing the opportunities of animal agriculture to contribute to poverty alleviation; the use of locally available resources and the reliance on indigenous services are thereby priorities.
- Innovations in subsistence agriculture must be developed and tested to ensure that they produce sustainable benefits. Better methods for the

> economic valuation of animal genetic resources, including their social and environmental externalities, in local production environments will be of particular benefit.
>
> These conclusions have broad application across a range of animal husbandry inputs and should not be thought of just in terms of genetic resources.

This can be achieved by planning for optimal output (milk, meat, fiber etc) rather than maximal output. Efficiency will often be enhanced by selection of lower input/output animals. Changing climatic conditions may also require changes to breeding schedules. The ability for farmers to manage this would be enhanced where accurate medium term climate predictions are available. For example if farmers are aware that drought conditions are likely in 3 months, they could make decisions such as early weaning of stock to take pressure of the lactating females.

(iii) Feed and water resources – Changing climatic conditions are likely to impact on pasture/rangelands. This may necessitate changes in the management practices for grazing animals e.g. dietary supplementation (protein, energy, minerals) may be needed. This could take the pressure off the pasture and improve sustainability. However, supplements are expensive, and may be difficult to obtain in many areas. Changing conditions could see a change in pasture plant species and an increase in tree growth, especially in areas where rainfall increases. There may be a need to change crops and cropping practices.

Water is not always available in sufficient quantity or quality to support animal production. Intensification of animal systems requires a greater need for water for drinking and cleaning. Changes in the distribution and amount of rainfall necessitate the need to ensure that the efficiency of water use is improved. Simple things like capping bores rather than letting water run through channels can substantially reduce water loss. Efficiencies can be improved by the development of practices that use less water (although in many regions water use is already minimal). There is a need to ensure that livestock enterprises are not established in areas where a lack of water (current or predicted) is likely to impact on future production. This would not be an efficient use of resources.

(iv) Health – Selection of animals for disease resistance and parasite resistance is important for efficient production. Given that disease vectors (e.g. insects) and parasites are likely to move into new areas as the climate changes, selection and breeding of livestock and poultry to meet these challenges must start now. Diseases and parasites can be managed by the use of drugs and chemicals but the cost is high. In most cases drugs and chemicals may be required to control endemic diseases irrespective of climatic conditions. Furthermore, prior knowledge of likely movements of diseases and parasites would enhance planning and ensure that farmers are prepared.

(v) Markets – Efficiency gains in animal production can easily be offset if animals and products can not reach markets. One of the major limitations in many regions is a lack of all weather road networks and transport infrastructure. Climate change models predict increases in the intensity of storms with the potential to substantially damage roads and bridges, thereby cutting market access.

In conclusion, the ability to adapt to change is paramount (ILRI 2006) for the sustainability of animal production. Education and training of people to adopt new techniques, while retaining local knowledge, will help to ensure that there is efficient use of resources in animal agriculture. However, success depends on planning, timely dissemination of information on impacts of changing climate at a local level, and engagement of communities. Using Farmer Field Schools would be of great help in developing countries (e.g. Minjauw 2002; DFID 2004).

References

Adams RM, Rosenzweig C, Peart RM, Ritchie JT, McCarl BA, Glyer JD, Curry RB, Jones JW, Boote KJ, Allen Jr. LH (1990) Global climate change and US agriculture. Nature 345:219–224

Chase Jr. CC, Riley DG, Olson TA, Coleman SW, Hammond AC (2004) Maternal and reproductive performance of Brahman × Angus, Senepol × Angus, and Tuli × Angus cows in the subtropics. J Anim Sci 82:2764–2772

DFID (2004) Livestock farmer field school. DFID Animal Health Programme. http://www.dfid-ahp.org.uk/index.php?section=3&subsection=22

FAO (2001) Agricultural biological diversity – lessons learnt from case studies on animal genetic resources. Subsidiary Body on Scientific, Technical and Technological Advice. 7th Meeting, Montreal, 12–16 November. FAO, Rome, 15pp

FAO (2008) Climate change and biodiversity for food and agriculture. http://www.fao.org/climatechange/49537/en/

Frank KL, Mader TL, Harrington Jr. JA, Hahn GL, Davis MS (2001) Climate change effects on livestock production in the Great Plains. Proceedings of the 6th International Livestock Environment Symposium. ASAE, St. Joseph, pp 351–358

Galvin KA, Boone RB, Smith NM, Lynn SJ (2001) Impacts of climate variability on East African pastoralists: linking social science and remote sensing. Clim Res 19:161–172

Gaughan JB, Mader TL, Holt SM, Sullivan M, Hahn GL (2010a) Using panting score to assess the heat tolerance of cattle. Int J Biometeorol 53, in press

Gaughan JB, Mader TL, Holt SM, Sullivan M, Hahn GL (2010b) Assessing the heat tolerance of 17 beef cattle genotypes. Int J Biometeorol 53, in press

Hahn GL (1999) Dynamic responses of cattle to thermal heat loads. J Anim Sci 77:10–20

Hoffmann I, Beate S (2006) Animal genetic resources – time to worry? Livestock Report 2006, FAO, Rome, pp 57–76

Howden SM, Soussana JF, Tubiello FN, Chhetri N, Dunlop M, Meinke H (2007) Adapting agriculture to climate change. PNAS 104:1969–1996

ILRI (International Livestock Research Institute) (2006) Climate change research by ILRI informs Stern review on the economics of climate change. www.ilri.org/ILRIPubware/

McManus C, Prescott E, Paludo GR, Bianchini E (2009) Heat tolerance in naturalized Brazilian cattle breeds. Livest Sci 120:256–264

Minjauw B (2002). Development of a farmer field school methodology for small-holder dairy farmers. DFID Animal Health Programme. R 7986. http://www.dfid-ahp.org.uk/index.php?section=4&subsection=128

Reilly J, Tubiello F, McCarl B, Abler D, Darwin R, Fuglie K, Hollinger S, Izaurralde C, Jagtap S, Jones J, Mearns L, Ojima D, Paul E, Paustian K (2003) US agriculture and climate change: new results. Clim Change 57:43–69

Steinfeld H, Gerber P, Wasenaar T, Castel V, Rosales M, de Haan C (2006) Livestocks long shadow: environmental issues and options. FAO, Rome, 391pp

St-Pierre NR, Cobanov B, Schnitkey G (2003) Economic losses from heat stress by US livestock industries. J Dairy Sci 86 (E Suppl):E52–E77

Thornton P, Herrero M, Freeman A, Mwai O, Rege E, Jones P, McDermott J (2007) Vulnerability, climate change and livestock – research opportunities and challenges for poverty alleviation. SAT eJournal | ejournal.icrisat.org 4:1–23

Tisdell C (2003) Socioeconomic causes of loss of animal genetic diversity: analysis and assessment. Ecol Econ 45:365–377

Voh Jr. AA, Larbi A, Olorunju SAS, Agyemang K, Abiola BD, Williams TO (2004) Fertility of N'dama and Bunaji cattle to artificial insemination following oestrus synchronization with PRID and PGF2α in the hot humid zone of Nigeria. Trop Anim Health Prod 36:499–511

Part III
Fields of Application in Agrometeorology

III.6.A.(v) Combined with 6.A.(vi) Selection Processes of (Changes in) Animal Husbandry and Combating Disasters in Animal Husbandry

Akinyemi Gabriel Omonijo

As to the first issue in Box III.6.7, determining the selection of areas for animal husbandry as part of appropriate land use and herding patterns, water is very essential for both man and animals. Consequently, the distribution of both man and animals is affected by the availability and reliability of water supplies. All sources of water on the earth's surface, whether streams and rivers or groundwater as springs or hand dug well water, ultimately come from precipitation. The distribution of precipitation over a given area provides a rough guide to the availability of water in such an area.

Box III.6.7

Weather and climate influence farmers' operational activities in animal husbandry, that is selection as a strategical issue and tactically as to the animal environment, directly or indirectly in three major ways (Ayoade 2002):

(1) They influence the availability of water for animal consumption and determine the type, quality and quantity of available animal feed.
(2) Weather and climate have direct effects on animals and their body physiological functions.
(3) They influence livestock production indirectly by determining the type of animal pests and diseases that would be prevalent in a given area.

The first two issues are dealt with in the bulk text of this paper, the third issue in Box III.6.8.

Unfortunately, moist climates are not very favorable for most types of livestock because of the variety of pests and diseases such climates encourage. Moist climates support forest ecosystems whereas livestock generally prefer grass

A.G. Omonijo (✉)
Department of Agricultural Technology, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria
e-mail: akingab@yahoo.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_91,

ecosystems, as grass is their major feed. Animal husbandry is therefore prevalent in the major grass ecosystems of the world such as the prairies of North America, the pampas of South America, the downs of Australia, the steppes of Russia and the African savanna amongst others. Within grassland ecosystems, areas with reliable sources of surface or underground water supply are usually well stocked.

Where surface water is not available, wells and boreholes are used to tap available groundwater to provide water for livestock. In the dry savanna zone of Africa, water is a major constraint to livestock rearing during the long dry season or in years of drought when the expected rain fails to fall. During such periods the surface water dries up and herders often resort to digging for water in the dry river beds, or may have to sell some of the herd to avoid losing them to thirst and starvation (Ademosun 1994).

As to the second part of the first issue in Box III.6.7, of importance for the selection of areas for animal husbandry as part of appropriate land use and herding patterns, climate and weather conditions also affect the quality and quantity of grasses available for animal grazing. This also applies to the growth, development and storage of forage crops which are used as animal feed. In the African Savanna where grazing is hardly supplemented with forage crops, the availability and nutritive quality of grasses for grazing vary with the season and the variability of rainfall from one year to another.

The quantity and nutritive quality of grasses are low during dry season and in drought years. This affects adversely the feeding of animals manifested as general loss of weight and marked reduction in milk production. In view of this, many migrate with their herds to more favourable climatic zones where more feed and water are available for their animals. In fact, this is the main reason why African cattle rearers tend to be nomadic.

In West Africa for example, there is large-scale movement of the Fulani cattle rearers from the Sudano-Sahelian Savanna zone to the moister Guinea Savanna zone at the onset of the dry season. When the rains come in the month of May, there is movement back to the Sudano-Sahelian Savanna belt. The animals lose weight during the migration towards South and later Northward and they are also exposed to trypanosomiasis during their sojourn in the Guinea Savanna zone. They then carry the disease with them to the Sudano-Sahelian Savanna zone which is naturally free from this disease (Kalu et al. 1991; Luckins 1992; Onwuliri et al. 1993; Ademosun 1994).

Drought is indeed a major constraint to livestock production in the African savanna and its strategical issues. Thousands of livestock perished during the West African Sahel drought of 1972–1974 as a result of thirst, hunger and disease and many more perished in the 1982–1984 droughts (Adefolalu 1984, 1999). In the temperate region, drought and low temperature in winter are major hazards to pastoral farming. Low temperatures adversely affect the growth of pasture. Hence, also in these parts farmers generally depend on pastures in form of hay already prepared in summer and stored for animal feed during winter (Adefolalu 1984, 1999).

For the second issue in Box III.6.7, of selection of areas for animal husbandry as part of appropriate land use and herding patterns, but also for tactical decisions on their environment, animals, like human beings, are directly affected by the atmospheric weather systems. Extremely low or high temperatures interfere with the physiological functions of animals (e.g. Johnson 1994; Hugh-Jones 1994). Following Oke (1978) (see for details also for example Hahn 1994), the energy balance of an animal can be written as follows:

$$Q^* + Q_M = Q_H + Q_E + Q_G + \Delta Q_S$$

where Q^* is the radiant heat load, Q_M is heat produced by metabolism, Q_H is the convective heat flux from the air to or from the animal when the air is warmer or colder than the body temperature of the animal, Q_E is heat used for transpiration and evaporation (the latter mostly when the animal is wet), Q_G is heat conducted to or from the lying animal from the ground when the ground temperature is different from the animal's body surface temperature and ΔQ_S is the net change in body heat storage.

Organisms are classified into two groups depending on the basis of the degree to which they internally control their thermal balance with their external environments (Oke 1978; Johnson 1994). In some organisms, the body temperature is dictated by that of the surrounding thermal environment. These are poikilotherms and they include plants and cold-blooded animals such as reptiles, fish and most insects. In contrast, homeotherms are able to maintain a relatively constant deep-body temperature irrespective of their thermal environment by various physiological mechanisms, which regulate their metabolic heat and loss or gain of heat by radiation, conduction, and convection. Warm-blooded animals, including humans, most mammals, and birds are homeothermic.

The precision to which this thermoregulation is achieved in these animals is known as homeostasis. Lack of homeostasis is indicated by high values of net change in body heat storage (ΔQ_S) causing a rise or fall in deep-body temperatures, a condition, which is harmful to the health of the animal. Thermoregulation in animals may be achieved by behavioral responses to the external thermal environment e.g. movement from one location to another with more conducive thermal characteristics, changes in body posture to control the size and the surface area of body involved in energy exchange with the environment, intake of warm or cold drink, and construction of shelter. Thermoregulation may also be achieved by physiological or involuntary responses to the external thermal environment, e.g. action of blood vessels, changes in pulse rates, sweating, panting or shivering etc. (Oke 1978; Hahn 1994).

The water balance of animals is also important as it is linked to that of the energy balance via the processes of transpiration and evaporation. The water balance of animals can therefore affect the physiological comfort of animals in a given environment. The amount of water held by an animal depends on its mass but the rates of transpiration and evaporation depend on the weather and the surface area of the animal.

It is not only the health of animals that is affected by weather and climate directly; the reproductive capacities of animals are also affected by weather and climate. Temperature affects the animal's physiological functions and biochemical reactions within its various organs and tissues which may affect its productive capacity. For instance, under hot conditions, dairy cows tend to produce less milk while beef cattle produce less fat and flesh. This is partly because these animals tend to reduce their intake of food when it is hot. Cattle generally likes grazing in shade locations better than in the sun and they normally rest in the afternoon when temperatures are high and sunlight is strongest. The degree of physiological discomfort felt by the animals in such weather conditions is high (Hahn 1994; Hugh-Jones 1994; Omonijo 2007).

The reproductive capacities of animals also tend to decrease under high temperature condition. Temperate breeds have been known to show a marked decline in fertility under tropical climate (Critchfield 1974; Johnson 1994; Hahn 1994). Until fairly recently, in selection processes little attention has been given to the question of the adaptation of livestock of temperate breeds to hot climate.

Livestock in a hot climate is influenced directly by heat radiation and humidity on the animal itself and indirectly by the effect of heat on the animal's environment (Webster and Wilson 1966; Hahn 1994; Hugh-Jones 1994). For any livestock to survive and be productive in the tropics, it must be heat tolerant. This implies that the animal must have a high efficiency of energy utilization and allow productive processes to continue at a high level without the production of excessive amounts of heat. Another effect of high temperature as prevalent in the tropics is to increase the water requirements of livestock.

The effect of extreme cold on animals may also reduce production. Much of the body energy is used to combat cold. Long exposure of livestock to cold may cause frost bite or even death. The water requirements of livestock may also not be satisfied under cold weather. Tactical arrangements must therefore be made to provide adequate shelter to keep animals warm and water for drinking requirements during cold periods (Oke 1978; Hugh-Jones 1994).

Table III.6.2 Related weather conditions and livestock diseases

Name of animal	Disease	Period/favourable weather conditions
Sheep, Cattle	Liver fluke	Wet summer
Young Lambs	Nematodiriasis	Onset of spring
Sheep	Facial eczema	Soil temperature (200 mm depth) 170 °C or soil moisture deficit 38 mm (Smith 1975)
Cattle	Windborne (foot and mouth disease)	High wind speed
Cattle, Goat	Trypanosomosis	High humidity, moderate high temperature (Omonijo 2007)
Goat	Pestes des Petit Ruminants (PPR)	High temperature, low humidity (Omonijo 2007)

Box III.6.8

Regarding the third issue distinguished in Box III.6.7 related to selection of areas suitable for animal husbandry as part of appropriate land use and herding patterns, weather and climate indirectly influence the health and productivity of livestock through their effects on the incidence and spread of pests and diseases that attack animals or the quantity and quality of forage crops and feed (Table III.6.2). Precipitation affects the quantity and quality of feed available to livestock. Range animals cannot move about and graze under heavy snow. Open grazing is not even feasible in winter when there is physiological drought and grass for grazing is not easily available.

Many of the restrictions on livestock productivity and regional distribution of livestock result from weather and climate conditions and their effects on livestock and the pests and diseases to which they are susceptible. For instance, in Nigeria, it has been argued already long ago that the humid southern parts of the country are as suitable as the drier northern parts for tropical cattle breed and more suitable for imported temperate breed because of the lower heat load on cattle in the South than in the North (Ojo 1971). However, the observed distribution of cattle and other livestock in Nigeria showed that larger populations of cattle were restricted to the Northern parts of the country. This is because the humid South is infested with tse-tse fly that causes cattle trypanosomiasis which is responsible for high rate of morbidity and mortality among cattle. The drier North is free from this insect and hence free from the scourge of this disease.

Tse-tse fly is found over most parts of Africa with the exception of the highland areas and the relatively dry areas. The tse-tse fly likes the tree canopies where transpiration and shade maintain a combination of high humidity and moderately high temperatures necessary for its growth and development. Consequently, only a few dwarf breeds of cattle that are resistant to trypanosomosis thrive in the humid and forested areas of Africa. Most of Africa's cattle populations are to be found in the tse-tse fly free zones of the African Savanna (e.g. Ojo 1971; Omonijo 2007). Finally, there is need for effective cooperation between the professionals that can contribute to high productivity of livestock in order to achieve optimum result (e.g. Hugh-Jones 1994).

References

Adefolalu DO (1984) On bioclimatological aspects of harmattan dust haze in Nigeria. Arch Met Geophys Biocl Sci B 33:387–404

Adefolalu DO (1999) Weather, climate and health. A Paper Presented During 1999 WMO Day Celebration, Lagos, no pages

Ademosun AA (1994) Constraints and prospects for small ruminants' research and development in Africa. In: Lebbie SHB, Rey B, Irungu EK (eds) Small ruminants' research and development in Africa. Proceedings of the 2nd Biennial Conference of the Africa Small Ruminants Research Network, Arusha, 1992. International Livestock Centre for Africa/Technical Centre for Agricultural and Rural Co-operation, Addis Ababa, pp 1–6

Ayoade JO (2002) Introduction to Agro Climatology. Vantage Publishers, Ibadan, pp 129–137

Critchfield HJ (1974) General climatology, 2nd ed. Prentice Hall, Englewood Cliffs, 465pp

Hahn GL (1994) Environmental requirements of farm animals. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 220–235

Hugh-Jones ME (1994) Livestock: management and decision making. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 291–298

Johnson HD (1994) Animal physiology. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 44–58

Kalu AU, Uzoukwu M, Ikede MM (1991) Trypanosomosis in Nigeria: high prevalence among ruminants in Gboko local government area, Benue State, Nigeria. Bull Anim Health Prod Afr 39:3–8

Luckins AG (1992) Trypanosomosis in small ruminants – a major constraint to livestock production. Br Vet J 148:471–473

Ojo SO (1971) Bovine energy, balance climatology and livestock potential in Nigeria. Agric Met 8:353–369

Oke TR (1978) Boundary layer climatology. McGraw-Hill, London, 372pp

Omonijo AG (2007) Weather variables and the occurrence of specific diseases of West African Dwarf (WAD) goats in Ondo State, Nigeria. Proceedings of the International Conference on the Impacts of Extreme Weather and Climate on Socio-Economic Development in Africa, Nigerian Meteorological Society, Akure, 1–15 November, pp 34–38

Onwuliri COE, Anosike JC, Nkem CN, Payne UK (1993) The ecology of animal parasitic nematodes in endemic areas of Jos, Nigeria. Appl Parasitol 34:131–137

Smith K (1975) Principles of applied climatology. McGraw-Hill, London, 233pp

Webster CC, Wilson PN (1966) Agriculture in the tropics. Longman, London, 488pp

III.6.A.(vii) Development of Microclimate Modification Patterns in Animal Husbandry

Silvia Valtorta

For an animal to maintain homeothermia, the environment and the animal must exchange heat at a rate that permits balancing the metabolic heat production and the energy exchanges. See for details Sects. III.6.A.(v + vi). In hot environments, energy exchanges by radiation are dominant, while convective energy exchanges tend to dominate in cold environments. Global climate change models predict an increase in heat stress events, as well as general warming in some regions (Gaughan et al. 2009). Therefore, environmental modifications to improve an animals microclimate become increasingly important. Nienaber and Hahn (2007) investigated ways to adapt current production systems in the face of a predicted rise in global temperatures (Box III.6.9).

Box III.6.9

Nienaber and Hahn (2007) discuss proactive environmental management as a means of reducing or eliminating livestock losses (animals and revenue) resulting from thermal challenges. The risk to livestock in the context of a heat challenge can be considered in terms of three elements: (i) perception, (ii) assessment and (iii) management. A risk assessment approach is presented. Their basic premise is that risk assessment needs to be based on animal (genetic, level of performance) and environmental parameters. From this, managers will determine the need or otherwise for environmental modification. Various environmental modification parameters are presented.

In order to change the microclimate of an animal effectively through housing or environmental modification, several factors, such as (radiant) temperature and emissivity of the surroundings, air temperature, air velocity, air vapor pressure, radiation

S. Valtorta (✉)
Investigadora CONICET INTA Castelar, Buenos Aires, Argentina
e-mail: silvia_valtorta@yahoo.com.ar

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_92,

or shade factors, and conductivity of surfaces that animals might contact, should be considered.

As a consequence, the effects of local weather are so important that the selection of a site for housing becomes fundamental. Observations of the microclimates in a general location will reveal much variation in thermal conditions. Also, the undesired impacts that modifications could have on microclimate should be considered, and environmental controls should be implemented. While some environmental modifications can improve performance in some conditions, they may be detrimental in other conditions.

Sprinkling can reduce the amount of dust produced by cattle movements in dry conditions (Mader et al. 2007), reduce insect avoidance behaviors and thus irritation for the cattle (Kendall et al. 2007), or improve milk yield in dairy cattle (Valtorta and Gallardo 2004). These responses may be an added incentive to install sprinkler systems in beef or dairy cattle farms. However, sprinkling cattle must be carefully monitored to ensure that it is not increasing the humidity too much. Where the humidity is such that it restricts evaporation and thus evaporative cooling, alternate methods of cooling must be considered. Excessive mud may also be an issue where sprinklers are overused.

Not only the environment, but also animal preferences and behavior affect microclimate selection (Mader et al. 2007). Thus, the best way to know the area of shade, that is adequate for a given location or environment, is to observe the behavior of the animals on the range, recording the average distance between them. The observed value can then be used in the planning of corrals and shelters. Da Silva (2004) presented formulas to predict orientation, shape and area of the shades projected by trees of different canopy shapes, considering location, year season, and time of day.

In Europe, the continually increasing number of design drafts required for building permits has rendered construction planning much more complicated. In contrast, the time available for planning is being constantly reduced. For this reason, the use of Information and Communication Technology in construction and cost calculation has been a focus for some time (Gartung et al. 2006). This kind of facts show how important it has become that routine tasks can be easily completed and information rapidly exchanged with networks of partners and databases.

Microclimate modification needs to be thoroughly planned and be low cost to build and maintain. Shade structures should be designed to maximize natural ventilation and protect animals from afternoon solar load. Reliance on fans in an area where electricity is not reliable is likely to lead to problems. Poorly designed shade structures (e.g. too low) may increase heat build up and lead to greater problems, especially where air flow is reduced.

As climate change becomes a major concern in animal husbandry, there is an increasing need to establish worldwide cooperation and networks to monitor the environment, not only from the standpoint of the effects it may have on animal production and health, but also considering the impacts either intensive or extensive production units may have on global warming, by increasing the concentration of greenhouse gasses (IPCC 2007). [See also for example Chaps. IV.14, IV.15 and IV.16.].

References

Da Silva RG (2004) Sol e sombra: importância da radiação solar para o conforto e bem-estar dos animais. Primeiro Simpósio Brasileiro sobre Sombreamento na Bovinocultura Tropical. [Sun and shade: importance of solar radiation for the comfort and well-being of animals. First Brazilian Symposium on Shading for Cattle in Tropical Environments], Jaboticabal, 20–21 October, 31pp

Gartung J, Hartmann W, Preiß F, Uminski K, Witzel E (2006) IT for the design of animal husbandry buildings. Section 6.2, Chapter 6, Management and decision support systems. In: Munack A (ed) Information technology, CIGR handbook of agricultural engineering, Vol. VI. ICAE/ASABE, St. Joseph, pp 367–382

Gaughan J, Lacetera N, Valtorta SE, Khalifa HH, Hahn L, Mader T (2009) Response of domestic animals to climate challenges. In: Ebi KL, Burton I, McGregor GR (eds) Biometeorology for adaptation to climate variability and change. Springer, Heidelberg, etc, pp 13–170

Intergovernmental Panel on Climate Change (IPCC) (2007) Agriculture. Fourth Assessment Report, Working Group III. Cambridge University Press, Cambridge, pp 497–540

Kendall PE, Verkerk GA, Webster JR, Tucker CB (2007) Sprinklers and shade cool cows and reduce insect avoidance behaviour in pasture-based dairy systems. J Dairy Sci 90:3671–3680

Mader TL, Davis MS, Gaughan JB (2007) Effect of sprinkling on feedlot microclimate and cattle behaviour. Int J Biometeorol 51:541–551

Nienaber JA, Hahn GL (2007) Livestock production system management responses to thermal challenges. Int J Biometeorol 52:149–157

Valtorta SE, Gallardo MR (2004) Evaporative cooling for Holstein dairy cows under grazing conditions. Int J Biometeorol 48:213–217

III.6.A.(viii) Improving the Issuing, Absorption and Use of Climate Forecast Information in Animal Husbandry

John Gaughan and Hesham Khalifa

Seasonal and year to year climate variations are influenced by interactions between the atmosphere and ocean and land surfaces (Hansen 2002). Improvements in understanding these interactions, advances in global climate models (e.g. coupled Atmospheric Oceanic Global Circulation Models: AOGCMs) and in monitoring sea surface temperatures (e.g. Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction: RAMA) have improved the predictability of seasonal fluctuations (Patt and Gwata 2002; Tarhule and Lamb 2003; Huda et al. 2004a; Osgood et al. 2008; McPhaden et al. 2009). However, problems remain in translating seasonal climate forecast information into appropriate action by livestock owners and livestock advisors (Huda et al. 2004a).

Climate variability has the potential to create problems with livestock production. However, there is also evidence that livestock production will increase in many areas, partly as a form of insurance against projected crop losses (Seo et al. 2008). Increasingly policy makers, agricultural advisors, livestock owners and managers need to undertake risk assessment in relation to climatic variability.

For livestock operations a "risk analysis should be based upon the probability assessment of the climatic events effecting the biological response" of animals (Decker 1997). The probability of high risk heat events has been undertaken for some livestock production regions (Hubbard et al. 1999; St-Pierre et al. 2003; Jones and Preston 2006). For example Preston and Jones (2006) suggest that a 2–3 °C increase in temperature will reduce the carrying capacity of Australian pastures by 40%. However, a lack of climatic data has limited this approach of coping with heat risks for many regions and locations.

Seasonal climate forecasting can forewarn government and non government organisations, farmers and livestock managers of adverse climatic conditions, and therefore has the potential to reduce risk (Hansen 2002; Patt and Gwata 2002; Osgood et al. 2008; McPhaden et al. 2009). Climate forecasts can be in the form of daily weather forecasts and advisories, 5- to 10-day forecasts and advisories, seasonal

J. Gaughan (✉)
The University of Queensland, Gatton, QLD, Australia
e-mail: j.gaughan@uq.edu.au

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_93,

forecasts and extreme forecasts (e.g. cyclones) (ADPC 2007). However, for longer term planning, forecasting out to 30 years should be necessary (Doherty et al. 2009). While short-term forecasts are often good, the medium-term and long-term forecasts are usually not as accurate, especially on a regional/local basis.

A significant factor limiting accuracy of predictive models is the lack of long-term climate averages for many regions (ADPC 2007). Therefore the focus of forecasting has largely been on a global scale. There needs to be an increased focus on downscaling climate information to regional and local scale if forecasts are to be incorporated into management practices (Jochec et al. 2001; Patt and Gwata 2002; Wang et al. 2004; Doherty et al. 2009). The establishment of a greater number of regional meteorological stations will improve the accuracy of climate forecasts. For example the establishment of an agrometeorological station at Dumangas, Iloilo Province, Philippines, in 2003, has improved forecasting activity in the province (ADPC 2007).

Given the problems, improved seasonal climate forecasts would allow livestock managers to be proactive in managing their resources (Jochec et al. 2001) (Box III.6.10). However, there are a number of factors which may impede or limit the uptake and use of forecasted climate information. These include (i) the target audience e.g. advisors and/or farmers, (ii) how the information should be used, (iii) what are the likely impacts on livestock production and (iv) how changes will be implemented (e.g. mitigation and/or adaptation) to offset the likely impacts (Hansen 2002; Patt and Gwata 2002). There is an urgent need to identify potential problems associated with the forecasted climatic conditions such as prolonged drought, and develop strategies to overcome or at least reduce the impacts on livestock production to ensure food security and economic viability of livestock production.

Box III.6.10

This material has been adapted from MLA (2007b). Roger Landsberg uses climate forecast information to make management decisions on his 32,000 ha beef property (Trafalgar Station) which is located near Charters Towers, Queensland, Australia (20° 6′S; 146° 16′E). The property runs approximately 3,000 cattle. The area relies on monsoonal rain which typically falls from December to February. However, monsoonal influences are not reliable so the area is often affected by drought (El Niño). Having a sound understanding of what climate forecasts means in relation to his property has allowed Roger to utilise this information in management.

The use of forecasting allows for the development of a planning strategy for adjusting breeder numbers before a below average wet season, allows time to plan selling strategies so that cattle are sold when prices are relatively strong (i.e. before everyone else sells after the wet season has failed). Alternatively if the forecast is for average or better rainfall, then there are opportunities to buy more cattle (cheaper) before it rains.

Pasture management is also influenced by seasonal forecasts. If the outlook is good, fire management can be used either to regenerate pastures or for weed control. If the outlook is poor, than grass is retained. Seeding new pastures or over-sowing with legumes is expensive and is undertaken when the outlook is for a better than average wet season.

If sufficient prior planning of stocking rates has been carried out, then there should be adequate feed to carry through the below average wet. In this situation, the budget allocated to pasture improvement may be better spent on water infrastructure to further drought proof the property.

The key points gained by using the forecast information are:

- Capitalising on strong livestock markets before a collapse due to drought affected animals flooding the market.
- Adjustment of stocking rates prior to a below average wet season, thereby maintaining herd condition.
- Planning pasture management e.g. burning or drought mitigation.
- Prioritise limited financial resources into infrastructure or pasture improvement depending on the season.

Climate forecasts deal in probabilities and a probability-based forecast is not a definitive forecast (DPI 2009). This is one of the major issues facing forecast information. The interpretation of forecasts by users and the wording of the forecast need to be assessed from the point of view of the end user (Childs et al. 1991). End users have difficulty in understanding the probability statements made in forecasts (Huda et al. 2004a; Keogh et al. 2005), with only 20% of respondents in a Western Australian survey correctly interpreting the standard wording of a probabilistic median rainfall forecast (Keogh et al. 2005). The concept of probability can be difficult to communicate and end users need to understand that a forecast not only predicts the probability of an event occurring but also the probability of it not occurring (Keogh et al. 2005).

It may be better therefore to present forecasts in more tangible terms, for example via the effect on pasture growth or stream flows, and how these will impact on livestock carrying capacity (see AussieGrass: www.longpaddock.qld.gov.au/AboutUs/ResearchProjects/AussieGRASS/) (McKeon et al. 2009). Additional problems are encountered given that the current forecast systems all have locations or times of the year when their forecast is no better than that based on rainfall records alone (MLA 2007a).

Further problems are encountered when the forecast is wrong. For example, in 1999 farmers in Tamil Nadu, India, were advised to apply fertilizer to their coconut trees due to anticipated rainfall – which did not eventuate. This costed the farmers approximately US$156/ha (Huda et al. 2004b). These factors may explain the high percentage of livestock managers that have little faith in climate forecasts and continue to use traditional forecasting methods (Sayuti et al. 2004), but there is a willingness of farmers to try modern methods of climate forecasts.

There are a number of strategies for improving the use of climate forecasts. George et al. (2006) discussed the effect of training and development and how this would enhance the knowledge and skills of people to apply forecast information. They concluded that professional development training improved knowledge and skills of people to better cope with a variable climate, enhanced decision making, and caused a reduction in climate risk exposure by applying models that used local data. Much of the forecasting is done remotely from the end-users. Engaging farmers in the process of forecasting (e.g. collecting rainfall) will help give them ownership, and may improve the use of climate forecasts in management (Huda et al. 2004b; Packham 2004).

Access to information will also improve the use of climate forecasts. The global RANET (**ra**dio and inter**net**) projects have tried to improve the usefulness of climate forecasts for livestock managers in a number of countries. RANET uses WorldSpace satellites to deliver image and text based material to very remote and rural parts of Africa and Asia. The system is a continental scale broadcast that can deliver satellite radio (audio) programming, as well as data. The unique advantage of the system for rural applications relates to the simple and inexpensive satellite receiver. No bigger than a typical personal FM radio, the system can be easily installed without support from a trained technician.

This program has the potential to deliver climate forecast information to those that otherwise would not have access to data (www.ranetproject.net/). For example RANET Ethiopia provides ten day, monthly and seasonal forecasts in three languages across eight regions (www.meteo-ethiopia.net).

Another important factor is to increase the lead in time for long-range forecasting, to allow for strategic and tactical decisions to be made (Huda et al. 2004b). Improvements in climate models, dissemination of forecasts in a manner that is easy for the end users to understand, development of strategies to deal with adverse climate forecasts and giving ownership of forecasts to end users will result in improved use of climate forecasts in animal management.

References

ADPC (2007) Report on the workshop on climate forecast applications for managing climate risk in agriculture. Asian Disaster Preparedness Center, Bangkok, 26pp

Childs IRW, Hastings PA, Auliciems A (1991) The acceptance of long-term weather forecasts: a question of perception? Aust Meteorol Mag 39:105–112

Decker WL (1997) Risk analysis in biometeorological applications. Int J Biometeorol 40:24–25

Doherty SJ, Bojinski S, Henderson-Sellers A, Noone K, Goodrich D, Bindoff NL, Church JA, Hibbard KA, Karl TR, Kajfez-Bogataj L, Lynch AH, Parker DE, Prentice IC, Ramaswamy V, Saunders RW, Smith MS, Steffen K, Stocker TF, Thorne PW, Trenberth KE, Verstraete MM, Zwiers FW (2009) Lessons learned from IPCC AR4 – Scientific developments needed to understand, predict, and respond to climate change. Bull Am Meteorol Soc 90:497–513

DPI (2009) Using climate forecasts. http://www.dpi.qld.gov.au/cps/rde/dpi/hs.xsl/4789_12952_ENA_HTML.htm

George DA, Clewett JF, Selvaraju R, Birch C (2006) Applied climate education and training for agricultural and natural resource management in India, Indonesia, Zimbabwe and Australia. J Agric Educ Ext 12:141–157

Hansen JW (2002) Realizing the potential benefits of climate prediction to agriculture: issues, approaches, challenges. Agric Syst 74:309–330

Hubbard KG, Stooksbury DE, Hahn GL, Mader TL (1999) A climatological perspective on feedlot cattle performance and mortality related to the temperature-humidity index. J Prod Agric 12:650–653

Huda AKS, Packham RG, Clewett JF, George DA (2004a) Introduction and overview. In: Huda AKS, Packham RG (eds) Using seasonal climate forecasting in agriculture: a participatory decision-making approach. ACIAR Technical Report 59, Canberra, pp 7–14

Huda AKS, Selvaraju R, Balasubramanian TN, Geethalakshmi V, George DA, Clewett JF (2004b) Experiences of using seasonal climate information with farmers in Tamil Nadu, India. In: Huda AKS, Packham RG (eds) Using seasonal climate forecasting in agriculture: a participatory decision-making approach. ACIAR Technical Report 59, Canberra, pp 22–30

Jochec KG, Mjelde JW, Less AC, Conner JR (2001) Use of seasonal climate forecasts in rangeland-based livestock operations in west Texas. J Appl Meteorol 40:1629–1639

Jones RN, Preston BL (2006) Climate change impacts, risk and the benefits of mitigation. CSIRO, Melbourne, 97pp

Keogh DU, Watson IW, Bell KL, Cobon DH, Dutta SC (2005) Climate information needs of Gascoyne-Murchison pastoralists: a representative study of the Western Australian grazing industry. Aust J Exp Agric 45:1613–1625

McKeon GM, Stone GS, Syktus JI, Carter JO, Flood NR, Ahrens DG, Bruget DN, Chilcott CR, Cobon DH, Cowley RA, Crimp SJ, Fraser GW, Howden SM, Johnston PW, Ryan JG, Stokes CJ, Day KA (2009) Climate change impacts on northern Australian rangeland livestock carrying capacity: a review of issues. Rangel J 31:1–29

McPhaden MJ, Meyers G, Ando K, Masumoto Y, Murty VSN, Ravichandran M, Syamsudin F, Vialard J, Yu L, Yu W (2009) RAMA – the research moored array for African-Asian-Australian monsoon analysis and prediction. Bull Am Meteorol Soc 90:459–480

MLA (2007a) Gauging the weather. In: Burke J (ed) Frontier – summer edition. Meat Livestock Australia Ltd., Nth Sydney, pp 9–10

MLA (2007b) Climate forecasts facilitate better management plans. In: Burke J (ed) Frontier – summer edition. Meat Livestock Australia Ltd., Nth Sydney, p 11

Osgood DE, Suarez P, Hansen J, Carriquiry M, Mishra A (2008) Integrating seasonal forecasts and insurance for adaptation among subsistence farmers: the case of Malawi. Policy Research Working Paper 4651, The World Bank, Washington, 28pp

Packham RG (2004) A background to participative approaches for research and application of climate science. In: Huda AKS, Packham RG (eds) Using seasonal climate forecasting in agriculture: a participatory decision-making approach. ACIAR Technical Report 59, Canberra, pp 35–41

Patt A, Gwata C (2002) Effective seasonal climate forecast applications: examining constraints for subsistence farmers in Zimbabwe. Glob Environ Change 12:185–195

Preston BL, Jones RN (2006) Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions. A consultancy report for the Australian Business Roundtable on Climate Change. CSIRO, Melbourne, 41pp

Sayuti R, Karyadi W, Yasin I, Abawi Y (2004) Factors affecting the use of climate forecasts in agriculture: a case study of Lombok Island, Indonesia. In: Huda AKS, Packham RG (eds) Using seasonal climate forecasting in agriculture: a participatory decision-making approach. ACIAR Technical Report 59, Canberra, pp 15–21

Seo SN, Mendelsohn R, Dinar A, Kurukulasuriya P (2008) Differential adaptation strategies by agro-ecological zones in African livestock management. Policy Research Working Paper 4601, The World Bank, Washington, 44pp

St-Pierre NR, Cobanov B, Schnitkey G (2003) Economic losses from heat stress by US livestock industries. J Dairy Sci 86 (E Suppl):E52–E77
Tarhule A, Lamb PJ (2003) Climate research and seasonal forecasting for West Africans – Perceptions, dissemination, and use? Bull Am Meteorol Soc 84:1741–1758
Wang Y, Leung LR, McGregor JL, Lee DK, Wang WC, Ding Y, Kimura F (2004) Regional climate modelling: progress, challenges, and prospects. J Jpn Meteorol Soc 82:1599–1628

III.6.B Cropping Under Cover

III.6.B.(i) Problems and Solutions in Coping with Extreme Meteorological Events in Agricultural Production, and Challenges Remaining for the Use of Science to Contribute to Problem Analyses and Designing Valuable Solutions in This Context: Cropping Under Cover

Kees Stigter

Cropping under cover is defined in Box III.6.11. Basic information on plasticulture is in Box III.6.12. In relation to non-forest trees there was already an introduction in Sect. III.5.4.(I) and in Box III.5.17 of that same section.

> **Box III.6.11**
>
> The terms "cropping under cover" or "protected cropping" point to a range of artificial devices and structures from cheap low plastic film tunnels supported by wire hoops, to glass and plastic film cloches, to traditional cold frames and modern solar frames, to "walk in" polytunnels, unheated and climatized greenhouses. Mulching films, made of plastic film or woven nylon, are considered also very useful forms of protected cropping (e.g. Larkcom 1997). Containers other than only for the root system also belong here and so do the labour intensive north-wall protected quarter-cylinder frames that the northern Chinese use, covered with plastic (and mats at night) (Stigter 2008). See for the latter also Box III.6.13 in Sect. III.6.B.(ii). Interaction with the radiation balance, the water balance and the exchange processes create the microclimatic differences (e.g. Stigter 1994). The higher temperatures and the

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_94,

absence of winds are the largest modifications, while plastic covered soils do hardly evaporate, planting holes apart (e.g. Stigter 2006, 2008).

When mulched with a woven product, water and nutrients will seep through. Embossment strengthens the film. Composition of such mulches (clear, black, red, silver, olive (Advance Greenhouses 2007)) determines radiation transfers, absorptions as well as reflections and therefore also influences microclimate in the space above it. Cover crops and other live mulches we do not count here because the material should be artificial. For many years, plasticulture systems of agriculture have been concentrated in developed countries but today research developments have made it possible to extend the benefits of the technology to less affluent regions of the world (Jensen 2004).

Box III.6.12

When considering the use of any system of plasticulture, the world may be divided into three geographic regions: (1) temperate, (2) semi-arid/arid and (3) tropical. In the temperate regions, all methods of protected agriculture are often used for early crop production and to produce summer crops out-of-season, during the winter. In the temperate regions, mulches add warmth to the root area; in tropical regions, mulches protect fruits from the disease or discoloration that might occur from contact with the soil. Row covers are commonly used during early spring in both the temperate and arid regions, but are seldom used in the tropics. One exception to use in the tropics might be the introduction of non-woven materials as protection against chewing insects or insects which are vectors of plant viruses (Jensen 2004).

The total world area of glasshouses is close to 50,000 ha, with most of these found in northwestern Europe. In contrast to glasshouses, plastic greenhouses have been readily adopted on all five continents, especially in the Mediterranean region, China and Japan. Most plastic greenhouses operate on a seasonal basis, rather than year round, as is the case with most glasshouses. PVC film for greenhouses is still dominant in Asia, especially Japan. Greenhouse structures are enclosed to provide temperature control and opened only to provide ventilation in both temperate and arid regions. In arid regions, during both summer and winter, evaporative cooling systems are commonly used to lower greenhouse temperatures. Closure also provides valuable protection from disease and pest infestations, and weather damage. Because of this, greenhouses are especially effective in tropical regions. In the tropics, the sides of a greenhouse structure are often left open for natural ventilation but if pest infestation is threatening the sides are covered with screens (Jensen 2004).

In addition to hail and wind damage, other risks incurred by users of cheap plastic structures without environmental control are low temperatures during winter, high daytime temperatures, unsatisfactory ventilation, high humidity at night, and a deficiency of CO_2 in closed greenhouses during the day (Robinson 1991). Greenhouse agriculture, as one of the more sophisticated forms of agricultural production under artificial cover, has in rather some cases another set of extreme events to fear and to fight compared with cropping in the open. An example is the following.

High evapotranspiration rates in the open may reduce the efficiency of irrigation and also cause topsoil salinization in hot regions. Cropping under cover such as in greenhouses considerably reduces evaporative water losses. However, ways of cooling the ambient temperature in the greenhouse are required. A once proposed project aimed at introducing high-tech but relatively low-cost technology for crop production in the Jericho region (INCD 1996). Greenhouses are very common in the Israeli Wadi Arava, as a measure of reducing evapotranspiration losses. However, much energy is required to cool these greenhouses.

The major asset of the proposed technology is a component that filters the incident sunlight, such that it allows in just the section of the photosynthetic spectrum, and significantly reduces the penetration of outside heat. This novel technology would enable lowering the temperature in a desert greenhouse at low cost. At the same time enrichment by CO_2 into the closed space is feasible, and this increases the tolerance of many crops to salinity. The greenhouse technology also saves lot of space and thus contributes to relieving the pressure on the diminishing soil resources of populated areas such as the Jericho region. The crops in the greenhouse can be grown on soil-less substrates, which enables irrigation that does not affect the soil itself, and leaves it uncontaminated (INCD 1996).

The use of plasticulture in the production of horticultural crops (vegetables, small fruits, flowers, tree fruits, and ornamentals) helps to mitigate the sometimes extreme fluctuations in weather, especially temperature, rainfall and wind. Many growers experience some extremes in weather conditions during the growing season that can kill or injure the crops, or reduce marketable yield. Row covers, low tunnels and high tunnels all have the potential to minimize the effect of these extreme weather events on the crop and optimize plant growth and development in a protected environment (Orzolek 2004). Plasticulture is a technical reality. Such production systems are extending the growing seasons in many regions of the world. They encourage conservation and preservation of the environment rather than the exploitation of land and water (Jensen 2004).

More recently, row covers and high tunnels have become popular with growers because of their simplicity and effectiveness in protecting crops from low temperatures in both spring and fall. They do not provide the precision of environmental control as that of conventional greenhouses, but they sufficiently modify the environment to enhance crop growth, yield, and quality. Although they provide a few degrees of frost protection, their primary function is to elevate temperatures each day and night over a period of several weeks. In addition to temperature control, there are also the benefits of wind and rain protection, soil warming, and in some cases control of insects, diseases, and predators such as varmints and birds. Overall, these systems should be considered protected growing systems that enhance earliness and higher yields, improve quality, and reduce the use of pesticides (Wells 2004).

Among the problems to be fought, degradable plastic mulches are receiving a great deal of attention, especially the photodegradable mulch. These plastic mulches have many attributes of standard polyethylene mulch: they are easy to lay and provide the usual benefits associated with mulch. The major difference is that photodegradable mulches decompose after the film has received a predetermined amount of UV light. Once it has received sufficient light, the mulch becomes brittle and develops cracks, tears, and holes. Like regular mulch, pieces of mulch are often blown away by the wind to adjoining fields or communities, except that the photodegradable pieces are usually less than 5–6 cm^2.

The photodegradable film will finally disintegrate into small flakes and disappear into the soil. Like regular mulch, the edges of the photodegradable mulch covered by soil will retain their strength and interfere with future tillage. Biodegradable mulches, while still in the experimental stage, will provide a huge breakthrough in reducing the cost of plastic removal from the field and eliminating the problem of plastic disposal. It will be important that the end products of biodegradable plastics be void of any undesirable residues, and that they be environmentally acceptable (Jensen 2004).

For glasshouses and more sophisticated greenhouses, the commercial approaches explain the statements that for growing protected crops, there is a need to know of extreme weather conditions such as very hot summers that will lead to increased sales of salad vegetables, and high winds that may cause damage to glasshouses and lead to increased fuel usage (Selman and Denis 1999). Shade and ventilation of glasshouses were repeatedly mentioned as needs in project documents, also as related to climate change issues in the industry (e.g. DEFRA 2004). Hail damage risks are obvious and protection by windbreaks and hail netting for the smaller units is also obviously possible commercially, as the internet abundantly shows.

The situation in the industrialized world is well described for the Netherlands by Elshof (2000) for the flower industry. A network of suppliers has developed around the growers, over the years becoming sufficiently specialized and sophisticated to enter the international arena. The network comprises breeders and propagators, seed companies, construction companies specializing in glasshouses, and companies specializing in the installation of utilities for glasshouses. Also connected are computer software companies who develop tailor-made systems to regulate the microclimate – humidity, air and light – inside the glasshouses.

Other branches serving the flower industry are banks, accountancy and administration firms, and insurance companies. The “Hagel Unie” (The Hail Union) has a long history of insuring glasshouses against damage by hail and other risks. The network has been an important reason for the continuous growth of the horticultural sector in the Netherlands. Open communication between small-scale units and service industries was facilitated by the well-developed physical infrastructure and the high level of education of the concerned parties.

References

Advance Greenhouses (2007) Plastic mulches, drip tape, and ground cover. http://www.advancegreenhouses.com/plastic_gardening_mulches_from_a.htm

DEFRA (2004) CSG15 Final project report. http://www2.defra.gov.uk/science/project_data/DocumentLibrary/CC0366/CC0366_2119_FRP.doc

Elshof P (2000) The Dutch flower sector: structure, trends and employment. Sector publication SAP 2.64/WP.120. http://www.ilo.org/public/english/dialogue/sector/papers/flrsect/flrsect2.htm

INCD (1996) Sub-regional Action Program for combating desertification in the Aqaba/Elat – Jericho section of the Jordan Rift Valley. http://www.bgu.ac.il/BIDR/MEPP/Subrap2.htm

Jensen MH (2004) Plasticulture in the global community – view of the past and future. http://www.plasticulture.org/history_global_community.htm

Larkcom J (1997) Oriental vegetables: the complete guide for the gardening cook. http://www.amazon.com/phrase/protected-cropping

Orzolek MD (2004) An introduction to plasticulture. http://www.plasticulture.org/what_description.htm

Robinson DW (1991) Developments in plastic structures and materials for horticultural crops. http://www.agnet.org/library/eb/331/

Selman JD, Denis C (1999) Seasonal weather forecasting and the requirements for the food supply chain. Foresight. http://www.foresight.gov.uk/Previous_Rounds/Foresight_1994__1999/Food_Drink/Seasonal%20Weather%20Forecasting/Index.htm

Stigter CJ (1994) Micrometeorology: Chapter 5. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 59–72

Stigter K (2006) Agrometeorological services in various parts of the world, under conditions of a changing climate. Austin Bourke Memorial Lecture presented in the Royal Irish Academy, Dublin, in the evening of 2 March. Extended Abstract available on the INSAM website (www.agrometeorology.org) under “Accounts of Operational Agrometeorology”

Stigter CJ (2008) Agrometeorology from science to extension: assessment of needs and provision of services. Invited lecture at the 50th anniversary of the Chinese Academy of Agricultural Sciences, Beijing. Agric Ecosyst Environ 126:153–157

Wells OS (2004) Season extension technology. http://www.plasticulture.org/history_season_extension.htm

III.6.B.(ii) Combating Disasters in Covered Cropping Systems

Zheng Dawei and Kees Stigter

There are three ways of combating disasters in agriculture: weakening disaster sources, strengthening crop resistance, and separating crops from disasters temporally and/or spatially. The latter can be done by adjusting sowing time or crop distribution and by covering cropping systems. People have always protected their crops from unfavourable climatic effects. Shrubs and walls protect against the wind, foliage and slats against harsh sunlight and driving rain, and glass against the cold (Van Heurn and Van der Post 2004).

The very old practice in Europe of cultivation under glass placed at a 60° angle against a wall, can still be found in China (Van Heurn and Van der Post 2004) but has largely been replaced there by the use of "quarter cylinder" plastic "sunlight greenhouses" with wind protection from an earthen wall (e.g. Stigter 2008; see also Box III.6.13). There is a similar sight in the highlands of Bolivia (Van Heurn and Van der Post 2004).

Box III.6.13 (Contributed by Zheng Dawei)

In the 1970s, some glass greenhouses with climate regulation were introduced in China from western countries but failed, due to high costs and low prices of vegetables. In the late 1980s, farmers in Liaoning Province created a new type of plastic greenhouse without heating, which is called "sunlight greenhouse" and has become the leading pattern of winter greenhouses in North China (e.g. Stigter et al. 2008). See also agrometeorological service example Sect. II.C.X in Part II. The size is similar to a normal greenhouse but there is a north wall with a height of 0.8–1.0 m and thickness of 0.6–0.8 m, made of soil or foam bricks. There is also thick matting made of straw on top for cover at night. Around the greenhouse, a ditch is digged and filled with heat insulating material.

Z. Dawei (✉)
Department of Agrometeorology, China Agricultural University (CAU), Beijing, China
e-mail: zhengdawei44@263.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_95,

When outside air temperature dropped to −15 to −20 °C, the inside temperature was still above 10 °C. In North China, vegetables could not grow in traditional greenhouses without heating in the winter. But now many temperate vegetables are produced. The slope of the top front sheet is designed for the local latitude in order to reduce reflection losses. It should be fastened before cold waves and strong winds, and the roof should be cleared after heavy snow in order to avoid collapse. The most serious disaster of "sunlight greenhouses" is continuous bad, gloomy and cold weather in late winter and early spring. If there are 7–8 overcast days, the soil temperature often decreases below 10 °C and causes diseases and freezing damage. Therefore, sunlight greenhouses should be thoroughly covered by straw matting at night to stay warm, and opened in the daytime for seedling hardening (see also Stigter et al. 2008 and agrometeorological service example Sect. II.C.X). Reflecting screens on the north wall and on the soil surface can improve reflection of radiation into the canopy. When it is very cold, ovens or electrical heating wires in the soil may be necessary.

Glass is the material that has been used through the ages to let light into a greenhouse. The discovery of transparent synthetic film was a groundbreaking development. It made the building of a greenhouse very much cheaper. Since recent decades, in many countries greenhouses and tunnels covered with plastic film are present. Indeed huge greenhouse complexes have sprung up in the highlands of East Africa and in the Andes region of South America (Van Heurn and Van der Post 2004). These changes and this spread have also consequences for combating disasters.

As far as the climate is concerned, besides protection against fluctuating temperatures, protection may also be needed against the sun's powerful rays (solar radiation), heavy rain, hail and strong wind. Crops often need to be protected against a combination of weather conditions such as these. The way in which crops can be protected to promote growth and improve the growing period can vary between simple and inexpensive methods to complicated capital-intensive ones (Van Heurn and Van der Post 2004). In China, the effects of different cover types are considered to include soil moisture conservation, warming, shading and protection from strong wind, hail, sand and dust storm. Due to improvement of field microclimate, crop yield and income obviously increase.

The simplest form of cover is to lay sheets of transparent plastic film (or something with comparable effects) on the ground. To ensure that the plastic film cannot blow away, the sides are weighted down with soil. This is a method that can be used in areas with a moderate climate in the spring. By covering the seedbed, a slightly higher temperature will be created and the moisture will be retained, which improves germination and growth of the young plant. Covering the ground with foliage or something similar is the cheapest method and something that is generally done in a sunny climate. A bit more structure can be added by a simple support and by placing screening material on top. The young plants will then have some room to develop freely (Van Heurn and Van der Post 2004).

In China, different kinds of cover are considered: ground cover and above ground cover, complete cover and incomplete cover in space and the same in time, the whole of the growing season or only one or more growth stages. The materials in China include plastic sheets and netting, soil, stone, gravel and stalks. Effects of such mulches have been discussed at various places in this book. The plastic seen as "white pollution" affects soil properties. Therefore, in China it is going to be replaced by degradable materials and farmers are encouraged to collect used sheets for reprocessing.

In some villages, farmers cut and harvest the top part of stalks for feeding animals, then break the remaining parts or simply press them down to cover the soil surface. In Heyang County, Shaanxi Province, the amount of precipitation that could be held in the soil increased this way from 25 to 50% after coverage. Yield of wheat and maize both increased more than 70%. At the same time, both water erosion and wind erosion decreased (Xin Naiquan et al. 2002).

Often, a smaller construction with stakes can also be erected above the nursery beds on top of which plastic film or vegetable screening material can be fixed in place, diagonally using wire, wood or bamboo. This offers protection, to a certain extent, against heavy rain and strong sun. It may be seen, small scale, throughout Indonesia for example. Open constructions such as these are most suitable for protection of the entire crop in the tropics. It will keep the plants drier and they will have less trouble with fungal diseases, so one will save on disease control. One will also get a better quality yield. To prevent the growth of weeds and to limit evaporation one could cover the ground with black plastic or straw. The plants will then be in holes made or left (Van Heurn and Van der Post 2004).

Low tunnels and small walk-in tunnels are actually miniature greenhouses. A variety of types have been developed comprising of a semi-cylindrical supporting framework covered with plastic film. The supporting framework can be made of hoops of wood, bamboo, plastic flexible tubes (as used for electricity wires) or strong wire. After stretching the plastic film (for instance, polythene or PVC) over the hoops, the sides can be weighted down with a layer of soil.

For ventilation, the plastic film can be lifted up or shifted a little. The plastic film is removed at harvest time and sometimes even earlier if the weather stays promising. Thus, the tunnel protects the crop in bad weather against low temperatures, hail and also from birds and insects. Low costs and a simple construction method are the most important advantages of low tunnels (Van Heurn and Van der Post 2004).

In China, in 2008, the total area of different greenhouses had increased to more than 2 million hectare. Plastic greenhouses are for example used there in vegetable and melon production in early spring and late autumn or in seedlings beds of early rice. In richer villages, farmers use steel structures with a life span of more than 10 years, while bamboo or wood structures with a life span of 2–3 years are used in poor villages. Heavy snow and strong wind give large damages if no special protection measures are taken, that are labor intensive.

The mean temperature inside has been measured in China to be up to 4 °C higher than that outside. Therefore, vegetable seedlings grow and mature quicker and the yield is much higher. But the temperature is often more than 50 °C in summer. The sheet should then be taken off or kept covering the soil to kill soil bacteria by solarization. Greenhouse temperature is adjusted by straw matting on top at night, electric heating in the soil, additional ground cover for warming, and by ventilation or uncovering for cooling according to different vegetables, growth stages and weather.

Humidity inside is often too high at night, which causes diseases. In the early morning, a lot of dew condenses on the sheet and decreases radiation by 10–20%. Therefore, ventilation is needed in the late night (Li et al. 2002; Wang et al. 2008). CO_2 concentration inside often decreases fast in the morning, due to strong photosynthesis. A fertilizer effect can be obtained by releasing CO_2 artificially and the yield can increase by 20–30%.

References

Li Mingfeng, Yang Wenganh, Ruan Shiming (2002) Microclimate character of plastic greenhouses and its relationship with vegetables cultivation. Hubei Meteorol 2002:27–29 (in Chinese)

Stigter K, Li Chunqiang, Zheng Dawei, Wang Shili, Ma Yuping (2008) Further identification of two agrometeorological services in Hebei Province, China. Information sheet resulting from a field mission in China in September/October. Available on the INSAM website (www.agrometeorology.org) under Accounts of Operational Agrometeorology of 17 November

Van Heurn E, Van der Post K (2004) Protected cultivation. Construction, requirements and use of greenhouses in various climates. Agrodok 23, Agromisa Foundation, Wageningen, 82pp

Wang Pengfei, Yu Xiujie, Bao Erlin, Yang Ning (2008) Plastic greenhouse optimization design and its thermal preservation. J Meteorol Environ 2008:27–30 (in Chinese with English abstract)

Xin Naiquan, Zhang Yanqing, Wang Ixiang (eds) (2002) The study of dryland agriculture in North China. China Agricultural Press, Beijing, 591pp (in Chinese, with English preface and table of contents)

III.6.B.(iii) Covering Crops to Improve Growth: Some Essential Experience

Kees Stigter (mainly choosing and editing material collected by Ernst Van Heurn and Kees Van der Post)

It was not that easy to find material on covered crops that fitted this book. There is much literature on greenhouses with climate control but little on the simple tunnels that would be helpful in developing countries. A good introduction, without literature but with websites, was provided by Carvajal Ortiz (2003). He mentions more yields, lower production costs, better prices, quality, lower use of water, early harvest and pest and disease control among the rationales and goals of indoor agriculture. He deals with snow, hail and wind as the meteorological limitations to be considered. Much of what is below has been taken from the even more useful publication by Van Heurn and Van der Post (2004). Low tunnels are further detailed in Box III.6.14 but were also already mentioned in Sect. III.6.B.(i) and dealt with in Sect. III.6.B.(ii).

Box III.6.14

Low costs and a simple construction method are the most important advantages of low tunnels. The disadvantages are that they only provide a limited temperature gain, opportunities for ventilation are very limited and caring for the plants (husbandry) is difficult. Low tunnels are usually used for only one crop. In most cases plastic film cover on the ground and low tunnels are the first steps towards protected cultivation. They could offer a temperature gain of 2 or 3 °C. For low-growing crops like lettuce, melon and the like, holdings often use low tunnels year after year as a proven remedy to force the crop.

Man-sized tunnels covered with plastic film are high enough for working in and for accommodating taller crops such as tomatoes and cucumbers. The simplest form of the walk-in-tunnel is made of wooden or steel hoops over which the plastic is stretched. It is important to make sure that the plastic

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia;
Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_96,

along the sides is anchored in the ground properly. The disadvantage of steel supports is that in the sun and at high temperatures the plastic film breaks down more rapidly where the plastic comes into contact with the hot metal. This can be avoided by insulating with strips of synthetic foam. Painting the plastic white above the hoops may help.

The plastic film can be fixed in parts across the tunnel or in the length of the tunnel. Fixing across gives the possibility to anchor the splits open for ventilation in between the length of the joints. If the length of the plastic film is laid lengthwise, a special anchoring is required at the end fronts, besides the side anchoring in the ground. The ventilation method for such tunnels has to be linked with the construction and cladding system. A simple tunnel has its limitations:

- In a warm climate, the simple means of ventilation limit the cultivation options.
- The use of cheap polythene (PE) film means that the covering will only last for one growing season because it will break down by the solar radiation and friction. This implies more costs for replacement and more refuse. Instead, you could buy UV-stabilised PE for a reasonable price, which will last a lot longer.
- Simple anchoring of the plastic film is vulnerable to storm damage.
- It is difficult to support tall crops properly.
- Freestanding tunnels are used on a large scale. They offer a crop some protection against the cold and, especially for tall and vulnerable crops, also protection against the wind and rain.

Experience has shown that limitations also arise as a result of excessively high temperatures and air humidity. Better ventilation is possible with some extra technical help, but it will also require some experience to be able to handle it (Van Heurn and Van der Post 2004).

The step towards tunnels in which the climate can be better regulated is simply a question of money. However, investing in such a step will only be justified when the grower has had the necessary experience with the crop in mind and with the monitoring equipment that will be needed. Exchanging experiences with colleagues, special advisers and suppliers will be a step in the right direction. In its simplest form, a multi-span greenhouse has a so-called flat-roof construction.

This type of greenhouse is mainly found in southern Spain. The plastic film covering is usually of a simple PE quality and must be replaced after every winter crop. The widths of the film are laid down on the whole length of the greenhouse. Ventilation splits are made between the widths of plastic film. And, because it lacks a sturdy structure, tall plants are supported with poles.

In regions with a dry sunny climate or in the dry season of a monsoon climate it is essential that the crops are protected against the blazing sun. A shade screen is usually placed above young plants, especially after potting or for cuttings. If this is going to be for a longer period, then a permanent screen will need to be placed. The easiest way would be to use leafy material like palm fronds, but woven cloth, netting or a lattice screen will last longer.

Screening materials vary in quality and in the degree to which they shut out the sunlight. The screening material can be attached to a construction of poles or tubing with squared horizontal brazing. The construction can be anchored on the sides for blistering sunshine. Ventilation (cooling) occurs via the open netting of the cover on the sides. They provide the opportunity for growing a diversity of crops without the need for escaping to the more complicated cooled greenhouses.

It is often necessary to heat the greenhouse or tunnel to prevent damage to the crop from the cold and to obtain optimum growth. Passive heating can be done by heat retention and actively one uses extra heating inside. Obviously, by covering the ground with plastic film and using tunnels and greenhouses, a part of the day's radiant energy can be retained. This is thus a form of passive heating.

A part of the sun's radiant energy can also be retained cheaply by placing black plastic film bags filled with water between the rows of crops on top of the soil. This water warms up during the day and gradually gives off its warmth to the greenhouse air. It is a pity though that towards morning, when the outside air is coldest, the release of warmth is also at its lowest. This inexpensive method is, furthermore, vulnerable because leakage can easily occur.

A better way to retain extra warmth is by choosing a more expensive plastic film for the greenhouse cover. The more expensive EVA-film is most frequently used for this purpose. You could also use a double layer of film to cover the greenhouse or tunnel. The disadvantage of this relatively more expensive method is that less light can be transmitted into the greenhouse, so that growth is retarded.

Energy screens have also been used for a few decades to reduce heat loss during the night. Considering that one already has a screen to shield against the blazing sun's rays, this can also be closed at night to keep in the warmth inside the greenhouse. There are screen materials that have been developed consisting of aluminium strips that can very effectively keep out the radiant energy, and as a rule these can also be used as shade screens. Of course investing in screens such as these is costly. The practice of rolling out (reed) mats over the greenhouse cover for the night has been around for a long time, although it is labour intensive.

Another very different age-old method of heating the soil is by using hotbed manure. By piling up fresh straw-rich manure and covering it with layer of soil, microbial fermentation producing heat. Thus the temperature of the upper surface of the soil rises and this promotes root development and growth of the crop. Furthermore, CO_2 is released, which stimulates the photosynthesis.

Adding straw enriched with nitrogen fertiliser and then wetting it can speed up fermentation. Straw in bales can also be used. They should be covered with

15–20 cm greenhouse soil after making sure that the straw has been thoroughly wetted and soaked with a nitrogen fertiliser. The temperature can rise to 30 °C or more, dependent of course on the amount used per metre.

Active heating of a greenhouse is also something that has been practised for ages. In its cheapest form, this is done by placing one or more heaters in the greenhouse and channelling the waste fumes upwards and out of the greenhouse via gradually ascending pipes. In this way you can try to get a certain degree of distribution of the heat output. In China they still use an ancient system in long greenhouses where a slightly sloping chimney runs all along the entire greenhouse, carrying the hot smoke from a stove burning in the front of the (lean-to) greenhouse.

Naturally, the further away from the stove the lower the temperature gets. More modern stoves distribute the heated air all over the greenhouse. These can be small hanging stoves in which clean (sulphur-free, because sulphur dioxide is toxic for the crops) fuel is burned (like propane gas, for instance). This of course does require the availability of electricity. The waste fumes containing CO_2 that is also useful for growth then remains in the greenhouse.

If the greenhouse does not need to be ventilated, assimilation can be boosted by this supply of CO_2 from the waste fumes as well as by a supply of pure CO_2. Toxic gases, including carbon monoxide and methane, are given off by incomplete combustion, which can cause serious harm to humans and crops. In addition, there are standing stoves that disperse the heated air in the greenhouse by means of a fan, but carry the waste fumes out of the greenhouse. Here, there is the risk of pollution via the greenhouse air. There is a whole range of them on the market.

References

Carvajal Ortiz M (2003) Indoor agriculture. In: Holden NM, Ortiz MC (prep) Agrometeorological aspects of organic agriculture, urban agriculture, indoor agriculture, precision agriculture. CAgM Report 90, WMO/TD 1158, Geneva, pp 53–74

Van Heurn E, Van der Post K (2004) Protected cultivation. Construction, requirements and use of greenhouses in various climates. Agrodok 23, Agromisa Foundation, Wageningen, 82pp

III.6.B.(iv) Selection Processes of (Changes in) Covered Cropping Patterns

Gerard P.A. Bot

As we saw in the previous sections, greenhouses protect crops from hostile outdoor conditions, so protect against wind, rain, hail and low or high temperature. Therefore they considerably improve crop growth conditions. In this way the growing season can be extended or it can even enable year round production, with production levels outranging outdoor crop production. They are also able to protect crops against insects, harmful by damaging or even destroying the crop or harmful as a vector for viruses. In this respect they also enable biological control of plagues. Moreover, the risk for the development of fungi can be decreased. For these reasons the interest in greenhouse cultivation is not restricted any more to the conventional greenhouse areas at moderate climates, but it is developing worldwide (e.g. Jensen and Malter 1995).

Greenhouses range from simple tunnels till high tech greenhouses with fully conditioned computer controlled indoor climate. Moreover, greenhouse facilities range from manual handling till fully automised logistics and crop handling. Active conditioning of greenhouse climate by implementing equipment for heating, cooling and supply of CO_2 and nutrient solutions enables optimisation of both product quality and production level (Bakker et al. 1995). However, already for some decades there are concerns regarding the high level of inputs of energy, crop protection chemicals and nutrients, which have to be applied with minimal impact on the environment (e.g. Bot 1992).

Growing a crop in a greenhouse demands new farmer skills in interfering with the greenhouse climate, aiming at improved crop production (Heurn and Van der Post 2004). In fact greenhouse air temperature is the grower's tool to control crop growth at the given solar irradiation. However, this has to be performed in combination with controlling humidity for realising good crop quality. The opportunity to control the combination of temperature and humidity in a greenhouse is a strong tool in crop

G.P.A. Bot (✉)
Retired from Wageningen University and Wageningen UR Greenhouse Horticulture, Wageningen, The Netherlands
e-mail: gerardenvera.bot@hetnet.nl

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_97,

production, but due to the interactions with the crop it is a complex task and linked to the demands of the particular greenhouse crop (e.g. for tomato: Heuvelink 2005).

For farmers the trend in the transition from open field cultivation to protected cultivation generally is to invest first in simple greenhouses and then stepwise improve their skills and invest in improved facilities (Zhang 1999). In this way most of the existing traditional greenhouse production areas have developed. Nowadays established greenhouse industry invests at high rate in high tech greenhouses in areas with attractive meteorological conditions, combining moderate outdoor temperatures with high irradiation levels and sufficient water availability.

For both simple and high tech greenhouses the mechanisms driving greenhouse climate are analogue. Understanding these mechanisms is a link to improve greenhouse growth conditions (see also Chap. IV.7). Two striking principles drive greenhouse climate to be different from outdoor climate (Businger 1966):

- The air in a greenhouse is stagnant due to the enclosure, so the air exchange with the surrounding (outside) air is strongly decreased compared with that of the air without envelope, and the local air velocities are small compared to that in the open air. These smaller local air velocities affect crop transpiration and sensible heat exchange, while the reduction of the air exchange (called ventilation) directly affects the temperature and vapour content of the greenhouse air.
- The inward shortwave irradiation is decreased due to the light interception by the opaque and transparent components of the greenhouse, while the long wave radiative exchange between inside and outside the greenhouse is influenced by the radiative properties of the cover materials. With glass as cover material, this mechanism leads to the mousetrap theory: glass is (partly) transparent for the incoming shortwave radiation and opaque for the long wave radiation emitted from within. However, this effect is of minor importance to an explanation of the increased air temperature in the greenhouse (Box III.6.15). Nevertheless, the radiative effects are indispensible to a description of the greenhouse climate because they explain the differences in greenhouse climate between greenhouses with different covering materials, like polyethylene (PE) and glass, having different radiative properties.

Box III.6.15 (Contributed by Kees Stigter)

Japan may be taken as an example where the history of selection processes of covered cropping patterns (plastic houses and glasshouses) and their causes have been well documented. Closest to agricultural meteorology this was dealt with by Takakura (1974). In 1950 the agricultural population of Japan was a bit lower than 50% of the total work force (lower than what it is today in China). By 1970 it had decreased to just over 25%. The decreasing labor supply caused increased efficiency of agricultural production, change from small hand operated plots to larger and more mechanized operations.

Such rapid developments made plasticulture of vegetables and floriculture in greenhouses an important segment of Japanese agriculture. The research objectives in agricultural meteorology kept pace with these rapidly changing developments. In the sixties plastic houses for vegetables increased from less than 1,500 ha to more than 10,000 ha, which remained around 90% of all plastic houses, while glass house area for vegetables came down from 43 to 29% of total glasshouse area, particularly due to the high costs involved.

In 1967, with at that moment more than 6,500 ha under plastic cover in Japan, only Italy had a somewhat comparable area under plastic houses, while the USA, USSR, Spain and France together had less than half of that (Takakura 1974). In addition to the greenhouse climate itself, it is necessary to keep in mind the most favorable conditions of growth for the crop, insofar as they are known (Businger 1966; Heurn and Van der Post 2004).

Already in the sixties it became clear that the "greenhouse effect" was a misleading concept of heat flow mechanisms within a greenhouse, although much later textbooks still gave wrong explanations (e.g. Seemann 1979). When the term was coined, it was thought to result from trapping the solar energy by reduced back radiation of longer wavelenghts by the optical properties of the glass. However, the largest thermal motive force raising the inside air temperature of greenhouses must be considered to be the suppression of turbulent heat transfer due to the cover materials (Businger 1966; Takakura 1974).

Already early in time some essentials for European conditions had been discovered, related to a higher transmission of sunlight in an E–W house than a N–S house, a more uniform light distribution in E–W houses, and consistently higher winter soil temperatures and heat gain in an E–W house than a N–S house (Griffiths 1966). Because the soil under the cover gains heat in daytime and looses it at night, conditions may occur in which inside air temperatures become lower at night than the outside temperatures (Takakura 1974).

However, Businger (1966) laments that in these early days remarkably little glasshouse climate research was reported during the many years of their use and I have the same experience from the earlier years with simple plastic greenhouses in China. It would be advisable if agrometeorological research in the tropics could also have a larger leg in understanding climate under simple cover. It is interesting to note that in Europe indeed (vegetable and flower) gardening was in the earliest periods the focus of greenhouse developments (Kanthak 1973).

The interception of solar radiation by the greenhouse cover is a disadvantage of greenhouses, while light loss means less driving power for crop photosynthesis. However, the resulting reduction in crop growth is compensated by the improved growth conditions during an extended growing season or even year round cultivation.

This is demonstrated in Fig. III.6.1, comparing average greenhouse production in some Mediterranean countries with that in the Netherlands. The figure also very roughly indicates at which average conditions heating or cooling has to be applied.

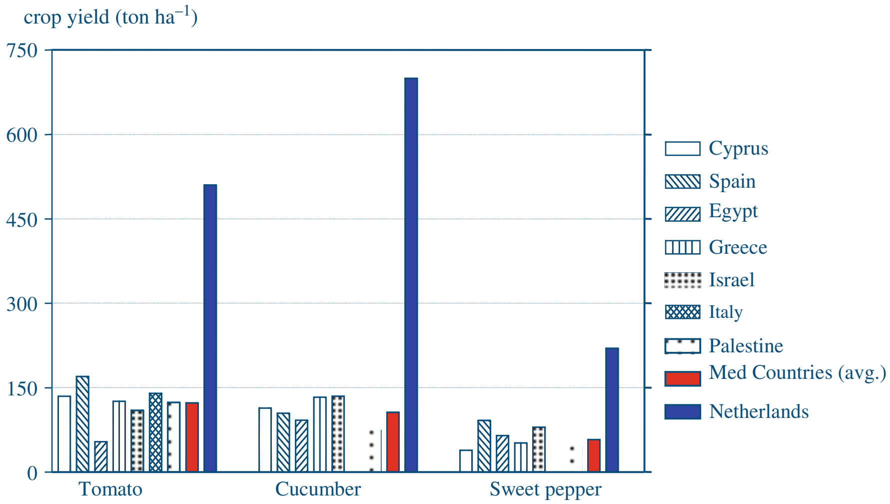


Fig. III.6.1 Comparison of greenhouse crop yield in countries with hot summer and cool summer climates (from HORTIMED 2004)

The striking differences can be understood from Fig. III.6.2 showing the climatic range in Northwest and Southern Europe. In the Netherlands cool summers and mild winters allow year round production. Moreover greenhouses are high tech with computer controlled climate conditioning. Winter conditions in the Mediterranean countries are favourable but summers are too hot for greenhouse cultivation. Moreover most greenhouses are simple plastic covered constructions without advanced climate conditioning. So, though the light conditions in the Netherlands and therefore potential productivity is inferior to that in the Mediterranean countries, this is more than compensated by better growth conditions and year round production. One has to be aware of the fact that the data give the average of daily averages, so instantaneous climate conditions can differ much from that indicated by Fig. III.6.2.

In conclusion, the starting point for greenhouse cultivation is enclosing the crop by a light transparent cover. For this situation already the above mentioned physical principles can be simply translated to characteristics of greenhouse climate behaviour, especially in dealing with greenhouse air temperature and humidity.

In Fig. III.6.3 solar irradiation is schematically compared for a covered indoor and uncovered outdoor crop. Both direct radiation and diffuse radiation are partially reflected and absorbed by the greenhouse cover and other greenhouse parts, and at

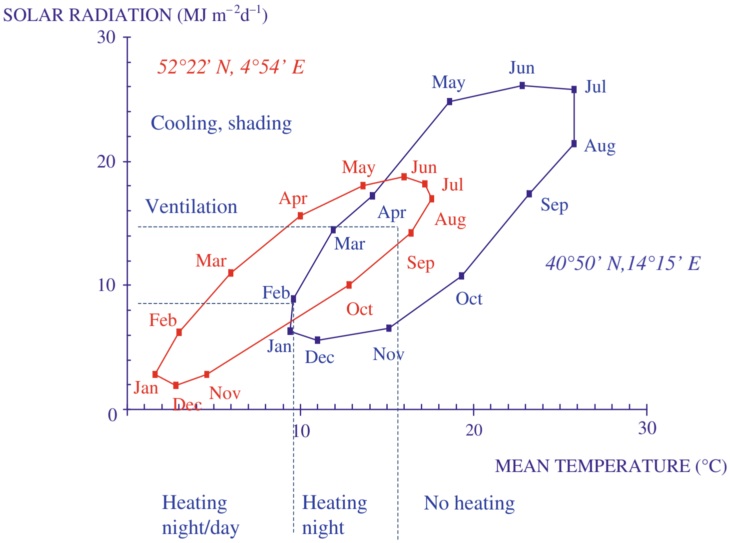


Fig. III.6.2 Outdoor climatic factors in southern Italy (40°50′ N) vs the Netherlands (52°22′ N) (from HORTIMED 2004)

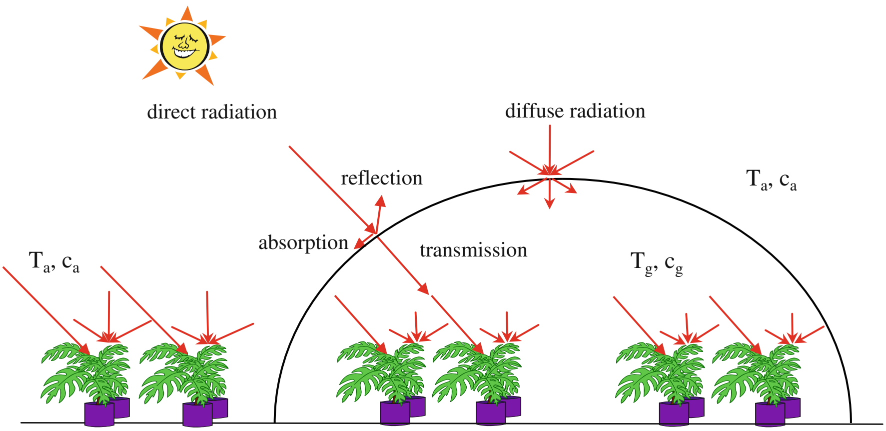


Fig. III.6.3 Solar direct radiation and diffuse radiation indoor and outdoor

crop level the transmitted irradiation available for crop absorption indoors is therefore lower compared to that outdoors. Light transmission of modern greenhouse covers is about 0.75 for diffuse radiation. Direct light transmission strongly depends on solar position, greenhouse geometry and orientation (Bot 1983; Critten 1993).

References

Bakker JC, Bot GPA, Challa H, van de Braak NJ (eds) (1995) Greenhouse climate control, an integrated approach. Wageningen Press, Wageningen, 279pp

Bot GPA (1983) Greenhouse climate: processes from physical to a dynamic model. PhD Thesis Wageningen University, 240pp

Bot GPA (1992) Greenhouse growing: outlook 2000. Acta Hortic 304:43–47

Businger JA (1966) The glasshouse (greenhouse) climate. In: Van Wijk WR (ed) Physics of plant environment, 2nd edn. North Holland Publishing Co, Amsterdam, pp 277–318

Critten DL (1993) A review of the light transmission into greenhouse crops. Acta Hortic 328:9–32

Griffiths JF (1966) Applied climatology. An introduction. Oxford University Press, New York etc., 118pp

Heuvelink E (ed) (2005) Tomatoes. CABI Publishing, Slough, 339pp

HORTIMED (2004) EU project HORTIMED deliverable. Contract number ICA3-CT-19999-009. Private communication by project leader Dr. C. Stanghellini, Wageningen University and Research Centre (WUR)

Jensen MH, Malter AJ (1995) Protected agriculture, a global review. World Bank, New York, 157pp

Kanthak P (1973) Klima und Klimatisierung von Gewächshäusern. [Climate and climate control of greenhouses.] Paul Parey Verlag, Berlin, 142pp

Seemann J (1979) Greenhouse climate. In: Seemann J, Chirkov YI, Lomas J, Primault B (eds) Agrometeorology. Springer, Berlin etc, pp 165–178

Takakura T (1974) Artificial climate. In: Mihara Y (ed) Agricultural meteorology of Japan. University of Tokyo Press, Tokyo, pp 126–153

Van Heurn E, Van der Post K (2004) Protected cultivation. Construction, requirements and use of greenhouses in various climates. Agrodok 23, Agromisa Foundation, Wageningen, 82pp

Zhang Z (1999) Update development of protected cultivation in mainland China. Chron Horticult 39(2):11–15

III.6.C Other Aspects: Fisheries and Aquaculture, Urban Agriculture, Precision Farming

III.6.C.(i) Problems and Solutions in Coping with Extreme Meteorological Events in Fisheries and Aquacultute, and Challenges Remaining for the Use of Science to Contribute to Problem Analyses and Designing Valuable Solutions in This Context of Fisheries and Aquaculture

Kees Stigter and Claude E. Boyd

Box III.6.16 explains the source of the material for this section. Fishers and aquaculture workers represented 2.8% of the 1.33 billion people economically active in agriculture worldwide in 2002, compared with 2.3% in 1990. Fishing in marine waters and inland waters roughly accounted for 75% of the total number of workers, while aquaculture production provided employment for the remaining 25%.

Box III.6.16

Although the draft version was submitted as agreed in 2007, Boyd and Pine (2010) only very recently published a first chapter of its kind in which agrometeorology and aquaculture and fisheries were connected in a review. The original version is available since 2007 on the CAgM and INSAM websites. The difference with the final version is language editing only. Because by September 2009 this final version was not yet available, we use this original version here as an important source of information.

Although aquaculture is likely to surpass in a not too distant future fisheries as the major source of aquatic protein, for the approach of this book classic fisheries and aquaculture will still be dealt with on an equal footing. This is because of the socio-economic problems related to such changes and the high importance that simple fisheries still has in developing countries.

In addition to catches (fisheries) and yields (aquaculture) being influenced by extreme meteorological events, information on the intensity and tracts of storms are critical to the safety of fishermen. Better methods for predicting

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_98,

the forces, paths, and conditions of storms and enhanced communications for warning fishermen of impending danger could save many lives.

In the future, developing countries (particularly Asian countries) will dominate food fish production, from both capture fisheries and aquaculture. Environmental controversy will continue: sustainability concerns will increase and motivate environmental regulations and environmental institutions, first in developed countries and then in developing countries.

Overfishing will remain a major concern. The link between pollution and food safety in the fish sector, including pollution sources outside the sector, will receive more attention worldwide (FAO 2004). Weather and climate issues will, even more than elsewhere, be related to information technology for improved fisheries management (e.g. FAO 2006).

However, areas of governance collapse, where for reasons largely external to fisheries (e.g. droughts, wars) pressure on resources will escalate, pushing more fisheries towards rapid decline and, possibly, collapse. Catches will definitively decline in quality and value. Fishing communities will face repeated crises and the disappearance of their livelihoods (FAO 2004). Coral reef areas are mentioned in Box III.6.17.

Box III.6.17

Coral reefs support more than 25% of the fishery production in many small island developing states, for the most part poor countries. Their degradation will be reflected in the composition of fish catches as well as the value of catches and adversely affect the food security of local dependent human populations.

Fisheries and coastal aquaculture in some regions of the world are known to suffer greatly from the effects of hurricanes, cyclones and earthquakes, particularly those that generate tsunamis, and especially in the most vulnerable tropical small-scale fisheries and in flood prone regions and small island states. Apart from the human and economic dimension of such disasters, hurricanes affect habitat, which may further exacerbate environmental stress, leading to a reduction of stock size and/or a shift in distribution. Unfortunately, the long-term effects of natural disasters may be unknown (FAO 2001).

In certain instances hydrologic and meteorological events cause microalgae in a bloom covering a wide area to be concentrated into one or several smaller areas. Very dense accumulations of the organisms occur, which can be very harmful to fisheries throughout the world (e.g. DFO 1994).

The ocean affects the rate of climate change and is in turn affected by it as well. Global warming could alter inputs of salt water, fresh water, oxygen, nutrients and pollutants with potentially large consequences for marine ecosystems and species. Changes in currents would also influence the recruitment of organisms in coastal waters and offshore waters. It has for example been reported that most of the decline in the world's marine fishery landings in 1998 can be attributed to changes in the Southeast Pacific, which was severely affected by El Niño (FAO 2001).

Ponds are discussed in Box III.6.18. In fisheries and aquaculture, the precipitation excess or deficit is a more important variable than precipitation alone. There are few places in the world where direct rainfall will sustain a pond. There usually must be one or more external water sources such as runoff from a watershed, inflow from seepage, or additions from wells or other water bodies.

Box III.6.18

Small, rainfed ponds are the most common aquaculture systems used by poor, rural people in tropical nations. Where direct rainfall is the major source of water for excavated ponds, ponds may dry up or become very shallow during the dry season. Embankment ponds are popular for commercial aquaculture, for water levels can be controlled and ponds drained easily to facilitate harvest. These ponds usually are dedicated to aquacultural use and are not sources of water for other activities.

Aquatic organisms also are cultured in open waters of oceans, estuaries, lakes, and streams by confining them at high density in enclosures or by placing sessile organisms on bottom plots or attaching them to a structural framework. Cages and net pens are constructed of netting secured to a supporting framework. There are also water recirculating systems. This short review from more elaborate stories in Boyd and Pine (2010) serves to imagine the various vulnerabilities to meteorological extreme events.

Drought can be particularly devastating in watershed ponds. Where groundwater is not available for refilling ponds, water levels may decrease drastically, causing overcrowding of fish. Finally, extreme weather events such as floods, droughts, hurricanes, and unseasonable temperatures can adversely influence water quality and have negative impacts on fisheries and aquaculture (Boyd and Pine 2010).

Forecasts of periods with heavy cloud cover could be useful in alerting aquaculturists to the likelihood of dissolved oxygen depletion and the necessity for preparing for the events. The likelihood of dangerously low dissolved oxygen concentrations in aquaculture ponds or in natural ecosystems increases appreciably during periods of abnormally high water temperature. Cold water and warm water species alike are stressed by abnormally high temperature. Prolonged exposure to high temperature will lead to diminished food intake and growth, disease susceptibility will increase, and mortality may occur.

Sudden episodes of cool weather can cause water temperature briefly to fall well below the monthly average and negatively impact survival and growth of aquaculture species. There are many examples for species of increased incidence of disease during periods when the air and water temperatures are either rising or falling. Aquaculture ponds in cold regions are likely to experience winterkill because they receive large inputs of nutrients and organic matter, and they tend to be shallow. Snow removal from ice is one way of lessening the probability of winterkill. Another method is to aerate ponds to circulate water and prevent ice from covering the entire pond surface (Boyd and Pine 2010).

Unusually heavy rainfall in coastal areas can cause extremely low salinity that stresses culture animals and leads to disease outbreaks or even causes direct mortality. Sometimes, heavy rainfall and associated runoff can cause rivers entering estuaries to change their course to affect aquaculture projects. Heavy rainfall during El Niño events causes such low salinity that it can stress or kill shrimp. Wind-induced currents can re-suspend sediment particles to create excessive turbidity, and they can cause erosion of pond embankments.

At sites where strong winds are common, vegetation barriers may be planted perpendicular to prevailing winds to provide windbreaks. Moreover, stone or plastic liners may be installed along embankments to minimize wave erosion. Grass cover should be established on above water portions of earthwork to protect against erosion by wind and rains. Ponds for shrimp farming and other types of coastal aquaculture are especially susceptible to storm damage.

There have been numerous instances of ponds being overtopped by storm surges and embankments breaching. Mangroves provide considerable protection from waves and storm surges in coastal areas. In some locations, the likelihood of storm damage has been exacerbated by the removal of mangrove forest for constructing ponds. Shrimp farms and other aquaculture farms should be constructed behind mangrove areas and the mangrove habitats left undisturbed (Boyd and Pine 2010).

On bright, calm days, oxygen concentrations may exceed 200% saturation. Life stages of culture species or natural organisms that cannot move into deeper water to escape the excessive gas pressure near the surface may be stressed or killed by gas bubble trauma. Strong winds or the combination of strong winds and heavy rainfall also may cause thermal destratification of ponds and lakes during summer. When sudden destratification occurs, low dissolved oxygen concentration may occur and fish kills may happen. Sudden thermal destratification or thermal overturns of lakes with cage culture operations can lead to dissolved oxygen depletion and massive fish mortality, which have been reported from Honduras and several Asian countries (Boyd and Pine 2010).

The importance of the use of weather forecasts and climate prediction as well as the understanding of water/pond and site microclimates is very clear from the above.

Knowledge of the frequency of excessive rainfall and floods, droughts, lower or higher than normal air temperatures, and destructive storms also would be beneficial. Armed with this information, aquaculturists would be able to plan and conduct operations. Aquaculturists could use local weather forecasts to prepare for adverse weather and decrease the likelihood of weather-related losses.

In fisheries a great priority probably should be given to predicting the influence that global climate change will have on production. Because aquaculture will eventually be the main source of fisheries products, it seems imperative to also assess the possible negative impacts of global warming on the major types of aquaculture.

On the other hand, decomposition of organic matter in sediment of aquaculture ponds produces carbon dioxide and methane that enter the atmosphere. It would be interesting to determine the contribution of world aquaculture to greenhouse gases (Boyd and Pine 2010). Also, concerns are often expressed about the environmental carrying capacity, which can be strained by increased numbers of farms and/or intensity of production systems. The production performance of the sector will depend on how well these issues are addressed (FAO 2006).

References

Boyd CE, Pine H (2010) Application of agrometeorology to aquaculture and fisheries. Chapter 13 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

DFO (1994) Offshore/inshore fisheries development. Red tides. http://www.mi.mun.ca/mi-net/fishdeve/redtide.htm

FAO (2001) Second meeting of FAO and non-FAO regional fishery bodies. Some external factors that may impact upon the work of regional fishery bodies and the management of fisheries. http://www.fao.org/DOCREP/MEETING/003/X9428E.HTM#P226_14836

FAO (2004) The state of world fisheries and aquaculture 2004. http://www.fao.org/docrep/007/y5600e/y5600e00.HTM

FAO (2006) The state of world fisheries and aquaculture 2006. http://www.fao.org/docrep/009/A0699e/A0699E02.htm

III.6.C.(ii) Agrometeorology and Urban Agriculture

Kees Stigter

There is no specific literature on agrometeorology of urban agriculture, of which the importance is illustrated in Box III.6.19. A just more than 100 pages CAgM report, on agrometeorological aspects of organic agriculture, urban agriculture, indoor agriculture and precision agriculture, has only two and a half pages as a summary of findings on urban agriculture (Holden and Ortiz 2003).

Box III.6.19

ETC (2003) gives among others the following examples to illustrate the importance of urban agriculture. On Java, Indonesia, homegardens provide for close to 20% of caloric consumption and 15% of protein intake of the urban population. In Hanoi, 80% of fresh vegetables, 50% of pork, poultry and freshwater fish, as well as 40% of eggs, originate from urban and periurban areas. In the urban and periurban area of Shanghai, 60% of the city's vegetables, 100% of the milk, 90% of the eggs, and 50% of the pork meat and poultry meat is produced. In Dar es Salaam urban agriculture is the second largest urban employer (20% of those employed).

Urban fresh milk production in Dar es Salaam was worth an estimated USD 7 million in 1993. The annual gross output of over 10,000 urban agriculture enterprises in the city of Dar es Salaam totalled more than 27 million USD, with an annual added value amounting to about 11 million USD. In 1991, the individual urban farmer's annual average profit was estimated at 1.6 times the annual minimum salary. In Nairobi in the early 1990s, agriculture provided the highest self-employment earnings among small-scale enterprises and the third highest earnings in all of urban Kenya.

Over 26,000 popular gardens cover close to 2,500 ha in Havana, producing 25,000 t of food each year; a total of 300 km^2 of urban agriculture produces

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_99,

close to 115,000 t year^{-1}. In Mexico City production of swine can bring in 10–40% of household earnings, urban cowshed-based milk can supply up to 100% of household income and in sub- and periurban areas maize production provides 10–30%, vegetable production and legume production even up to 80% of the household income.

Of the six definitions given there, the one saying that urban agriculture is defined as "the procurement of food products through crops, animal husbandry, forestry and aquaculture within urban zones and in fringe areas, for improving the nutrition of population groups, generating employment and income, for individuals or groups of individuals, assisting environmental sanitation through recycling waste waters and solid wastes" is most comprehensive and close to how we experience it.

However, good additions are that (i) products are usually processed and marketed by the producers and their close associates; (ii) it is carried out on roadsides, along railroads, in backyards, on rooftops, within utility rights of way, in vacant lots of industrial estates, on the grounds of schools, prisons and other premises and (iii) it includes aquaculture in tanks, ponds and rivers; orchards and vineyards; trees in streets and backyards, on steep slopes and along rivers.

If we want to assess how urban weather and urban climate differ from that outside the built environment, Holden and Ortiz (2003) state that the possible magnitude of climate change (now roughly set between 1° and 4° by the year 2100) has to some extent already occurred in some big cities. Over the past 100 years, Tokyo's average temperature has increased by about 3 °C, and that of Osaka has increased by about 2 °C. Since it is said that global warming has raised Japan's average temperature by about 1 °C, the temperature increase due to the Urban Heat Island (UHI) effect is probably about 2 °C in Tokyo and about 1 °C in Osaka (Edahiro 2008). Also others confirm that the urban influence on its climate is presently a lot higher than that of present climate change (Mariani and Sovrano Pangallo 2005).

At night cities are warmer than their rural surroundings because of heat stored in bricks and concrete and trapped between close-packed buildings, which indeed is the UHI effect (see also the case study on urban temperatures in built and green environments in Box III.6.20). City wind speeds, although lower on average, are with tunnels and hot-spots, where winds are channelled down city streets or wash down the faces of tall buildings. Wind protection may then be needed.

Box III.6.20

Air temperature distribution in the city of Florence was studied in three different settings: street, garden and courtyard (little garden of less than 500 m^2) surrounded by walls. Air temperature was also analyzed according to the distance from the center of the city, the mean number of buildings per km^2 and their mean height. As a result of this study, higher air temperatures were found in the center of the city and just near of it. These zones are even characterized by a smaller quantity of green areas, by a higher urban density and by higher mean height of buildings.

Moreover, it is in these areas that the higher air temperature differences between streets and gardens were found. It is important to underline that green areas inside the city behave, as to air temperature, as rural areas surrounding the city do. At the beginning of the day (up to 8 a.m.), air temperature increases faster in the gardens than in the street, to maintain the same value or a bit lower one during the afternoon, and to reduce suddenly in the evening, when in the street temperatures stay high for many hours (Petralli et al. 2006).

Rainfall capture and rainfall conservation are necessary for sustained crop growth. Direct sunlight can give problems because unwanted shading has to be taken into consideration but artificial shade may be necessary for long hours of full sunshine in the tropics. High humidity levels are particularly common in tropical cities and maritime cities. Ambient air pollution in and around cities can have serious negative effects on yields and nutritional qualities (Holden and Ortiz 2003).

Greening is an effective approach to mitigating the UHI effect (Edahiro 2008). According to surveys by the Tokyo metropolitan government (Tmego), when the temperature of concrete surfaces rose to 55 °C in mid-summer, the surface in green areas was as low as about 30 °C. Another new idea that has cropped up is to plant grass along tram lines. Greening on walls and with rooftop gardens has been a common measure, and recently more and more people have begun to grow climbing plants such as morning glory and bitter gourd on nets or frames outside the windows of their homes as green curtains of vegetation.

Measures for dealing with pavement surface heat, water-retentive pavements and/or insulating pavements are being adopted more widely. The Tmego conducted an experiment in which a total of four kilometers of water-retentive pavement was installed. The results showed that this type of pavement cooled down the road surface temperature by about 10 °C.

In addition, applying thermal barrier coating to roofs, to reflect sunlight, throws off heat to a remarkable extent. The Tmego, together with the governments of seven Tokyo wards, and seven other organizations, established a “Committee to Promote Cool-roof” that promotes measures to deal with both the heat island effect and global warming through rooftop greening and thermal barrier coating (Edahiro 2008).

Annotated bibliographies with reviews in certain fields of agrometeorology date back more than 15 years (e.g. Stigter et al. 1992). Much has happened in agrometeorology since. A scientific approach of the urban boundary layer complexities with its phyto-elements does exist (see Box III.6.21). The absence of agrometeorology in urban agricultural literature is illustrated by conclusions in a review paper (Deelstra and Van den Biggelaar 2003) on city ecology in a recent annotated bibliography on urban agriculture (ETC 2003):

Box III.6.21

One may state that in agrometeorology we have different scale elements of agricultural and urban phytocoenosis (the whole body of plants occupying a particular habitat) that are the subjects to interact with the meteorological elements. Models being able to describe the conditions of numerous elements of agricultural or urban phytocoenosis, should definitely include scaling – the transitional description of models of a single phyto-object and the meteorological field with which it interacts up to the numerous objects inside a characteristic Representative Elementary Volume (REV) together with the meteorology fields scaled for that volume. Part of an urban environment, and such a critical one for the air quality, are the phyto-elements as trees and a grass covering. In many occasions phyto-elements are almost inseparable from the buildings.

Studies of a turbulent boundary layer with a rough or porous subsurface are conducted on a common theoretical basis called the boundary layer theory. Experimental and theoretical works cover a wide range of roughness types and cover the scope of processes taking place. Because of unspecific mathematics and general ambiguities in other theoretical scaling approaches, one can notice that the same models and equations are often employed to simulate turbulent (and other) processes in media with very different morphological properties, making the model insensitive towards the most important viz. the morphological specifics of media in which a process is occurring.

If the media, which overall properties are sought, are known as being dependent on the lower (smaller) scale physical phenomena, then the latter physical and mathematical descriptions need to be considered and constructed in a way incorporating the interdependence with the higher (larger) scale descriptions and mathematical modeling into the lower (smaller) scale and vice versa (Travkin 2009).

- There is a substantive body of research on urban agriculture, dealing with its incorporation into the urban ecosystem, with respect to recycling nutrients, wastewater and solid waste.
- Fewer studies have been done on the role of urban agriculture in urban climate management.
- Some studies are available which deal with polluted environments effecting food and consequently human health.
- Studies of the impact of urban agriculture on environmental components such as groundwater and soils are scarce.
- Also the benefits of urban agriculture for the urban ecosystem with respect to multiple use of space are not well researched yet.
- Often, urban ecological research is pure observation of what happens in the realm of urban vegetation, groundwater management and microclimate. Urban agriculture studies focus in particular on cases.

- Guidelines or generic models to promote urban agriculture as a component of sustainable urban ecosystems are not yet available. It is recommended that more studies should be done on how to incorporate urban agriculture in the flows of water and energy in the urban ecosystem.
- Also environmental risk assessment is an important subject to focus on.
- Macro-urban ecological studies, in which conclusions are drawn about the degree of self-reliance with respect to food and timber in relation to geographical features and regional characteristics, would help to build strategies for improving urban ecosystems towards sustainability. Unfortunately, very little has been produced on this subject.
- Within the framework of Agenda 21, an enormous task lies ahead to limit the impacts of cities on their wider environments. The knowledge collected so far on urban agriculture indicates that it is likely that further development of urban agriculture can substantially help to reduce urban ecological footprints. Given the potential role of urban agriculture for the sustainability of the urban ecosystem it would be important to formulate a specific research agenda. A key research area is to analyse scenarios and strategies with respect to the role of urban agriculture as a "cleaner" as well as its role in reducing flows (of food, energy, water, nutrients, raw materials, and transport) from urban hinterlands to cities.

References

Deelstra T, Van den Biggelaar M (2003) Urban agriculture functioning in urban ecosystems. Section 1.3: Urban agriculture and the city ecology. In: Annotated bibliography on urban agriculture, ETC, Leusden, The Netherlands, pp 171–211. http://www.ruaf.org/node/695

Edahiro J (2008) Efforts in Japan to mitigate the Urban Heat Island effect. Japan for sustainability. Available at the INSAM website (www.agrometeorology.org) under "New information for agrometeorologists" of 1 October

ETC (2003) Annotated bibliography on urban agriculture. Leusden, The Netherlands, 804pp. http://www.ruaf.org/node/692

Holden NM, Ortiz MC (preps) (2003) Agrometeorological aspects of organic agriculture, urban agriculture, indoor agriculture, precision agriculture. CAgM Report 90, WMO/TD 1158, Geneva, 101pp

Mariani L, Sovrano Pangallo G (2005) Approccio quantitativo all'analisi degli effetti urbani sul clima [Quantitative approach to the analysis of the urban effects on climate] Riv Ital Agrometeorol 10(1):31–36

Petralli M, Prokopp A, Morabito M, Bartolini G, Torrigiani T, Orlandini S (2006) Ruolo delle aree verdi nella mitigazione dell'isola di calore urbana: uno studio nella città di Firenze [Role of green areas in urban heat island mitigation: a case study in Florence]. Riv Ital Agrometeorol 12(1):51–58

Stigter CJ (coord & ed), with contributions from Karing PH, Stigter CJ, Chen W, Wilken GC (1992) Application of microclimate management and manipulation techniques in low external input agriculture. CAgM Report No. 43, WMO/TD-No. 499, WMO, Geneva, 192pp

Travkin VS (2009) Fundamentals of hierarchical scaled description in physics and technologies. http://travkin-hspt.com/agrom/bot.htm

III.6.C.(iii) "Paleez Khoursheed": Agrometeorology for Precision Farming in Iran

Alireza Sodagari and Kees Stigter

"Precision farming" or "precision agriculture" is an agricultural concept relying on the existence of in-field variability. It is about doing the right thing, in the right place, in the right way, at the right time. It requires the use of new technologies, such as a global positioning system (GPS), sensors, satellites or aerial images, and information management tools (GIS) to assess and understand variations.

Collected information may be used to more precisely evaluate optimum sowing density, estimate fertilizers and other input needs, and to more accurately predict crop yields. It seeks to avoid applying inflexible practices to a crop, regardless of local soil/climate conditions, and may help to better assess local situations of disease or lodging (Griepentrog 2008).

This definition with the requirements as given here is typically one applying to high input farming of richer large scale farmers. In this book the approach of Holden (2003) fits a lot better. He mentions that synonyms include "site specific farming", "site specific crop management", "targeted agriculture" and "prescription farming". The latter issues also apply to labour intensive LEISA farming with affordable inputs and a wish to improve such inputs, such as found in poorer and technologically less advanced countries.

Precision farming may be used to improve a field or a farm management from several perspectives (Griepentrog 2008):

- agronomical perspective: adjustment of cultural practices to take into account the real needs of the crop (such as better fertilization management)
- technical perspective: better time management at the farm level (such as planification of agricultural activities)
- environmental perspective: reduction of agricultural impacts (better estimation of crop nitrogen needs implying limitation of nitrogen run-off)
- economical perspective: increase of the output and/or reduction of the input, increase of efficiency (such as lower cost of nitrogen fertilization practice).

A. Sodagari (✉)
Orchardist/Grower, Selling Agromet Systems in the Country, Shiraz, Iran
e-mail: k536_project@hotmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_100,

Other benefits for the farmer may be to help him/her set a history of his/her farm practices and results, to help him/her in his decision making and traceability requirements (as increasingly required in developed countries).

This again fits high input farming better but is already closer to Holden's (2003) assessment that the farmer starts by collecting data, which will usually be in the form of a yield map (even when only stored in his/her own memory), and probably more detailed soil and environmental data. This is then interpreted to create application maps/strategies for management of the production stage, and the result quantified in the next year's yield map. The idea is that as more and more data are collected, better informed decisions can be made about how best to manage the farm (Holden 2003). Such types of precision farming are also found in so called homegardens in the tropics (e.g. Landauer and Brazil 1990).

This last section in Part III now continues to deal with a case study in Iran that is closer to Parts I and II of this book and to the above given synonym "site specific crop management", where it is about learning as much as possible about an orchard with multiple fruit trees using site-specific agrometeorological data and preparing site-specific agrometeorological services, among others to better cope with disasters.

Iran has faced several consecutive years of drought. Moreover, last winter (2007/2008) was a special year which recorded the lowest temperature in 40 years. The cold winter was followed by frost by early spring. Adaptation to natural disasters, and lowering the impacts of severe weather conditions on agriculture, seems to be a challenge for the Iranian farmers.

The project reported on here started in February 2005, wanting to practise the application of agrometeorological information in farm management and orchard management. Adaptations to natural disasters, interaction with the environment, as well as improvement of agriculture knowledge bases, are the other goals of this project. The project site is ten hectares of land located in Iran's south-western province of "Fars" at an elevation of 1,722 m, with a latitude of $29^\circ\ 36'$ N and a longitude of $52^\circ\ 30'$ E.

Application of agrometeorological data in orchard management and adaptation to natural disasters is achieved in five categories:

- best environmental adaptation by site selection and site preparation;
- drought risk management and drought risk adaptation through optimized irrigation;
- frost management;
- pest management and diseases management;
- multiple cropping and sustainable economy.

Meteorological data were studied to find the site meteorological specifications. This step was done before any action in the orchard. The site was selected based on the weather data collection of previous years and direct measurement of key parameters on-site for 22 months prior to inauguration of orchard establishment. Taking into account the weather data as well as soil profiles and water profiles, types and varieties of crops were selected. Meanwhile the natural risks such as flood, frost and drought were evaluated. The plant’s substrate was prepared and mixed with organic compost to increase the water holding capacity of the orchard soil.

As the whole country (Persia) is located in the dry area of the planet, water availability/drought is the most important factor of agriculture. Agriculture uses 93% of the country’s water resources, while 60% of the agricultural water is coming form deep wells. Frequent rain shortages and “dry years” are the most common natural phenomena and risks. Fars province, with 110 watershed areas, is the largest agricultural region in Iran that has 618 watersheds in total. The average rain rate is 320 mm $year^{-1}$ for the project area.

A proper irrigation system was installed for the orchard and meteorological data were used to schedule the irrigation amount and frequency. The most important agrometeorological issue in irrigation is evapotranspiration of the crop (ETc). This variable is calculated from several meteorological parameters. The Penman/Monteith equation, based on wind, temperature, humidity and solar radiation, was used in calculation of ETc. This has been referred to in other parts of this book. The monthly ETc related to a specific crop is determined and amounts of irrigation will be set based on this parameter, considering the phenological phase of the crop and soil characteristics.

Soil moisture was measured by planting a relative sensor in the root zone of the crop. The soil moisture data were used to define “When to irrigate”, while the ETc value determined “irrigation amount”. Total ETc for the project site was 1,590 mm $year^{-1}$. Quantity and quality of irrigation are constantly monitored for optimum water consumption and to lower the drought impacts. Monthly irrigation based on ETc related to the specific crop shows that the accumulated irrigation amount is proportional to the accumulated evapotranspiration values (Fig. III.6.4).

Agrometeorological data were also used in frost warning as well as to define a proper measure to deal with different frost conditions. Frost warning can come from decreasing temperatures, but an earlier warning comes from the weather station based on the dew point values at sunset. This warning gives a probability of frost conditions in the morning following this sunset.

This warning method will provide an about 10 h preparation period before the actual frost condition. The relevance of the relation between frost probability and dew point is shown in some actual data of the 2008 spring (Fig. III.6.5). The dew point reading on April 2, 2008, at 18:30, was −10 °C and the air temperature reading on April 3 at 06:00 was −5 °C. The same phenomena happened in the next day of frost conditions.

Another system was developed to monitor the temperature drop in the orchard. A frost warning alarm was made of a solar powered digital thermocouple and a siren. The thermocouple is monitoring the critical temperature and the trend of it in a “decreasing” rate. As the alarm can be distributed via GSM modems or automatic dialers, it will be a useful help for the other farmers with a similar microclimate in the area too. This method of frost warning will provide a more precise forecast of

Fig. III.6.4 Showing daily ETc, accumulated ETc and accumulated irrigation over time, with a constant K-factor

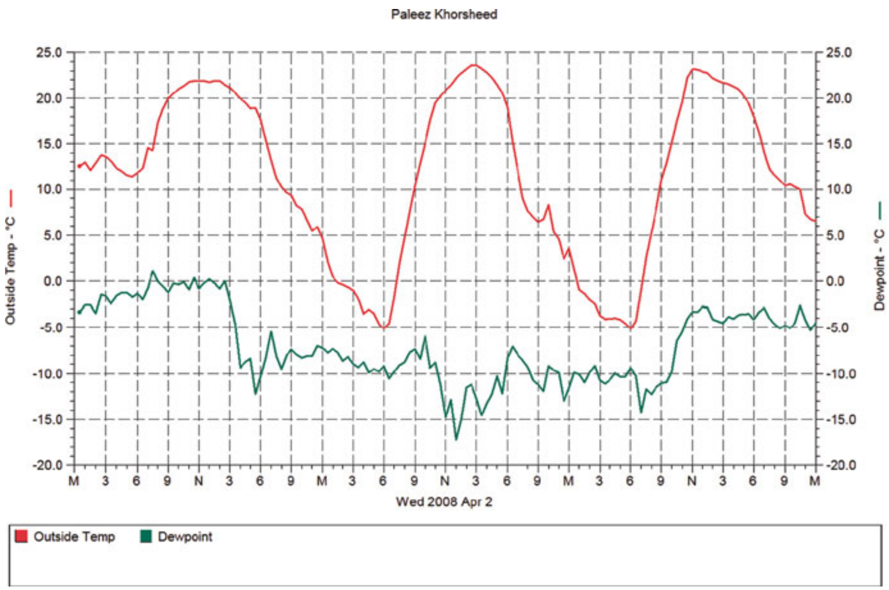


Fig. III.6.5 Dewpoint of just over −10° around sunset of 18.30 h is related to frost of −5° nearly 12 h later on two consecutive days frost conditions, but only a few minutes ahead of the actual frost condition, unless another threshold is built in.

Cover crops have environmental benefits to the orchard. Increase of bio-mass, soil erosion reduction, fertilizer efficiency improvement and water penetration are such benefits. Moreover, the cover crop is also used to balance the temperature extremes in the orchard. Results of the first year of experiments were quite satisfactory.

Irrigating the orchard overnight significantly reduced the frost damages. Considering the special microclimatic conditions in each site, a proper frost protection method can be proposed. For this site, some more effective frost protection methods are under investigation and development.

Based on the experiments carried out on this site, other frost adaptation methods have been developed for other sites too. In other orchards, frost protection was achieved by balancing the humidity of the site. Small fountains, pumping the water into the air with low amounts but high pressure, were installed to increase the humidity of the orchard.

Based on the agrometeorological data recorded at the project site, "wind" can be proposed for some cases as an important factor in frost protection. Following observations shows that the frost conditions happened in the no wind or low wind conditions.

Flood and rain storm situations could be forecasted for the site as the moisture profile of the soil is known and the rain rates and wind speeds are also monitored constantly in the orchard. In Iran, floods have higher frequency and cause more damages than earthquakes. In other words, flood is the disaster number one in the country. The installed weather station on the site is accessible via wireless LAN and can be downloaded or broadcast alarms continuously.

Although the orchard is not yet bearing fruit, the first steps for coping with disease risks were taken. Codling moth is the main threat to the orchard. The related biofix and risk management phenological model are specially developed and will be fine tuned for the microclimate. Degree days and chilling hours reports are other agrometeorological parameters implemented in orchard management. The degree days report will be used to track the pest and diseases in the orchard, while the chilling hours report will be used to monitor the required periods for proper fruit bearing of the trees. In case the required amount is not reached, compensation can be made by application of proper supportive chemical agents, if not polluting the environment or poisoning the consumers. A sample of the report is presented here (Table III.6.3).

Soil temperature is another agrometeorological parameter which is used to monitor the nematodes activities. Also for spraying time and general labor schedules, wind speed and temperature are the meteorological data which have been considered.

The orchard trees are walnut, apricot and apple as the main crops and peach and sour cherry are used as the filler trees. Alfalfa is planted in the tree rows as the cover crop. Agrometeorological data will enable the farmers to manage multiple crops at

Table 1 III.6.3 Sample of a "degree days" report

Degree days Report 08/05/07	
Codling moth 1st Gen	
Start date	: 07/10/10
Base temp	: 10.0 °C
Upper temp	: 40.0 °C
Total for previous 7 days:	
08/05/03	: 3.7
08/05/02	: 5.3
08/05/01	: 6.9
08/04/30	: 8.2
08/04/29	: 7.1
08/04/28	: 6.3
08/04/27	: 6.1
Total	: 175.9
Development total	: 260.0
Deg days left	: 84.1
Days to go	: 12.4

the same time as well as to perform better coping strategies with risks. Consequently, the farmer would have a more secure source of income.

Improvement of agricultural economy will enhance the living standards (such as housing) and may cause better preparedness for non-agricultural disasters such as earthquakes, which are also frequent in Iran. Agrometeorological data collection will lead to a "smart" precision farming which in time will reduce the pressure on natural resources.

References

Griepentrog H-W (2008) Definition of precision farming. The centre for precision farming. Faculty of Life Sciences. University of Copenhagen, Copenhagen. http://www.cpf.life.ku.dk/about/definition.aspx

Holden NM (2003) Precision agriculture. In: Holden NM, Ortiz MC (preps) Agrometeorological aspects of organic agriculture, urban agriculture, indoor agriculture, precision agriculture. CAgM Report 90, WMO/TD 1158, Geneva, pp 75–101

Landauer K, Brazil M (1990) Tropical home gardens. United Nations University Press, Tokyo, 257pp

IV.1 Introduction to Part IV

Kees Stigter

There are and will be no agrometeorological services and no agrometeorological action support systems without supportive scientific methodologies as workable tools and approaches. Modern assessments of climatic resources, water resources, soil resources and biomass resources are unthinkable without such technologies (Stigter et al. 2010). In a book like this, it is not about an explanatory approach to these methodologies but about exemplifying how these methods are supportively applied as tools and approaches; to get operational results in problem solving in the agricultural environment that is the livelihood of farmers. So it is shown how they guide certain fields towards the operational applications in Part III as well as how they contribute to derive the examples of Part II and make them work, including the related educational commitments.

In Part I it was explained in Sect. I.3.2 that going from the C-domain to the B-domain involves an upgrading of the operational qualities of the scientific support systems. It was argued that this upgrading is actually mostly driven by general agrometeorological action support systems for mitigating impacts of disasters (E1) and more occasionally by making use of the windows of opportunity that weather and climate offer. At the very first CAgM session I participated in, Baradas (1983) so eloquently showed a great example of the latter windows of opportunity by proposing the use of drier parts of the year for crop production in the humid tropics. With his emphasis on impounded water, microclimate modification and practical things that can be implemented by farmers he had apparently gone in Asia the same way we went in Africa since the late seventies (see Chap. IV.9).

We claimed in Sect. I.3.2 that problem solving in the livelihood of farmers necessarily needs another increase in the operational use of agrometeorological knowledge, by applying the mixture of the B-domain into actual agrometeorological services (E2), supporting the decisions and actions of producers. Part III illustrates that

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_101,

B-domain, and it does so in a way that it can act as a source of educational revival and renewal in applied agrometeorology through case studies and their backgrounds.

Having separated basic and applied sciences completely, the Part IV of this book is on scientific support systems not from the scientific point of view but from the applied angles. An improvement of the guidance that E1 should give in action support to reach the B-domain with appropriately selected and better operationalized support systems contents. There are a sufficient number of publications on the science concerned. The shelves are well stocked.

Al Riebau (personal communication 2009) for example reported that the United States' NOAA and the US Department of Energy promote the exchange of data between the major climate modeling centres and are working actively on the detection of anthropogenic climate change on regional scales and in climatic extremes. Some early results, using a standard optimal detection formalism, are indicating an anthropogenic signal in North American and Eurasian surface air temperature data (NOAA 2009). Evidence of anthropogenic change is also being detected in other parts of the climate system.

For example, changes are being observed in the global oceans that are consistent with anthropogenic forcing of the climate system. Also, an anthropogenic signal has been detected in sea-level pressure data and in changes in tropopause height. In addition, there is a growing interest in the question of whether there has been an anthropogenic influence on observed changes in precipitation extremes and temperature extremes. There has been some preliminary work on the detection of such changes (Zwiers et al. 2003; Zwiers and Zhang 2003). We can leave such important questions to the C-domain. Here we want to show that bridge to the B-domain to have available the most useful contemporary pools of knowledge and to show the conditions required.

Tools and approaches in various supportive fields are shown for the four main contents distinguishable in the C-domain of support systems: (i) data; (ii) research; (iii) education/training/extension; (iv) policies. We give a summary below in the sequence of these four components, but the sequence chosen for the 20 chapters is that of ethical issues and their relation with policies (Chaps. IV.2–IV.5) first; policies and applied science guided by policies (on data and applications) (Chaps. IV.6–IV.16) second; and applied science as guided by tools (Chaps. IV.17–IV.20) last.

For the "data issue" we have a Chap. IV.6 on "Meteorological data to support farming needs" and the bridge function is already in the title. It states that the management of agrometeorological data in the electronic information age has become easier, faster, and more efficient. Yet, management of the data is perhaps one of the most critical processes in any design concept. There are several key areas where attention needs to be directed as one considers any particular design requirements, including data collection, data processing, quality control, archiving, data analysis and product generation, and product delivery.

However, it warns, when the technology is made available, limited resources and capacity building opportunities often restrict the application of technology. Recent technological innovations are becoming more cost-effective and user-friendly, which is allowing greater utilization among the developing countries, but it is still beyond the means of poorer nations without donor support.

It also warns that data base management is meaningless if the information itself is not readily available in a friendly format to the user community in time for appropriate decision making. There must be more critical consideration for local needs and for emphasizing the local bottom up determination of how agrometeorology may help farmers solve their local needs.

For the "data issue" we also have a Chap. IV.9 on "*Field quantification*". It concludes that presently a big difference with the African work described in its case studies is the actual quantifications taking place these days. One may first observe from the contents of the journal Agricultural and Forest Meteorology that in agricultural meteorology, field quantification is particularly still taking place in regard to studying processes. That is the main stream research in agricultural meteorology. The quantification of phenomena in the agricultural production environment has become much less important in the western world, largely due to simulation modeling applications. In developing countries quantification in agricultural meteorology has remained negligible. One difficulty is that the quantification should of course change compared to say what we did 50 years ago. In the scarce field research, a connection with actual farmers' problems is often missing.

Such problems are presently mainly addressed by NGOs in participatory approaches in which field quantifications play only a very modest role, with the exception of on-farm rainfall observations. As we have shown in Part II of this book, agrometeorological services can gain a lot from quantitative field research supporting design and understanding of improved services. In China this idea is slowly winning support, but no results have been communicated before. In India, Vietnam and South Africa there are possibilities for the advance of such approaches. See Parts II and III.

In the combination of "data and their research use" we have Chap. IV.17 on "*Modeling and simulation*", that particularly aims at showing the limitations of the approach. Models, as complementary tools to field experiments, are simplified versions of the real systems (prototypes) and none of them can either represent the real processes in the real systems in sufficient detail or be assumed universal, due to complexity and scale dependence of involved processes, their natural variability and purpose of the modeling itself.

Modeling can be perceived mainly as a framework for testing new theories and hypotheses in order to improve our understanding. For a good mathematical model, however, it is not enough to work well. A good fit of a model to measured data is often only a result of overparameterization of the different processes involved. The model must work well for the right reasons. Otherwise, we are still in the danger aptly formulated in that "(...) our technological successes have simply made us more efficient at being stupid".

It is recommended that modeling studies should include the phases of: (a) determination of a general or site-specific problem, (b) conceptualising important properties, processes, and events, (c) quantitative definition of the problem or developing and validating a computer code, (d) calibration of the model and collection of independent data for evaluating its prediction capabilities, and (e) developing new prediction techniques in order to solve the defined problem.

In the further combination of "data and their research use in case studies" we have as Chap. IV.10 and IV.11 two contributions on "*Agrometeorological statistics*". In the first it says that statistical methods are useful to organize, present and reduce observed data in a form that facilitates their interpretation and evaluation. Concerning data and the related investigations it is first necessary to recognize the different information going with the data: metadata and nature of the data. Subsequently it is needed to identify missing data and evaluate the quality of the data with specific statistical methodologies, depending on the variables. Three case studies problems are then dealt with.

Illustrations of statistics are given with frequency distributions in the second contribution. Changes observed in monthly rainfall may be due to changes in the number of rain days, in rainfall intensity, or both. Examples focus especially on extreme rainfall, and try to provide updated information on trends and interdecadal variability in southern South America that could provide useful information for decision making under conditions of a changing climate. The case studies presented here also illustrate the value of statistical analyses in preparing the determination of complicated cause and effect relationships between climate and yields.

Chapter IV.20 on "*Geoinformatics for evaluating erosive rainfall hazards in uplands crops: preliminary decision making*" is an elaborated case study of even more complicated statistics, illustrating the use of GIS for erosion evaluation. Extreme erosive events have been observed as increasing in recent decades and they are expected to rise during warm periods.

It is then important to gain a better understanding of the forcing mechanism and its predictability. This work could be improved and developed considering some guidelines such as: (i) establishing a better knowledge of the rainstorm frequencies that may exceed specific thresholds (e.g. tolerable soil loss), and historical disaster records; and (ii) employing a more inclusive planning process using a multi-criteria approach to select the appropriate land-utilization types and to plan agro-ecological land use.

Another combination of "data and their research use in case studies" is in Chap. IV.18 on "*Monitoring and early warning*". It starts with an overview of the Energy and Water Balance Monitoring System (EWBMS) and the data involved. Then an appropriate growth model is used in combination with the data from the EWBMS. Given the EWBMS temperature, radiation and evapotranspiration fields from the satellite we may estimate for each pixel the biomass increase, starting from an initial biomass at germination. After 70 growing days the ratio between "actual" biomass and "potential" biomass, called the relative biomass, becomes constant. This observation is the basis of the crop yield forecasting approach.

It is argued that crop growth models are usually not very accurate. The simple model discussed is a simplification of reality. The more complex and detailed models however suffer from high input requirements on soil, crop and cultivating practice, which are usually not available. Given this consideration, the model generated biomass data are used in a relative way. During the summer of 2007 10-daily crop yield forecasts were published for West Africa and East Africa on the UN humanitarian website Reliefweb. Potato yield forecasts have been made for Europe and a coffee yield forecast was generated for Rwanda.

Part IV continues with "data and their research use in case studies" in Chap. IV.19 on "*Remote sensing*". The development of space technology has led to a substantial increase in satellite earth observation systems. The benefits of a wealth of observational data, derived products and internal services from specially equipped and highly sophisticated environmental satellites have reached the meteorological sciences and associated environmental disciplines such as hydrology and oceanography. The same applies to agricultural meteorology.

Drought is a regional event which can be monitored and assessed using ground and remote sensing information. Satellite based indices are widely used to monitor drought occurrence and intensity in both time and space. This information can be used by the government for farmers to establish mitigation measures such as tax relief, no-interest loans, etc. Remote sensing methods are becoming increasingly important for mapping land use and land cover, because, among other advantages, large areas can be imaged quickly and repetitively. The analysis process essentially involves the transformation of remotely sensed measures of spectral radiance into information about the composition of the land surface.

As earlier dealt with in this book, there remains an actual danger that these applications are technology driven and not need driven. The agrometeorological community has to serve the actual needs of farmers with an up to date knowledge of those needs in agrometeorological services and advisories. The present limitations have recently again been spelled out.

Fully in the field of "research that supports decision making", so still in the research type of contents, are the chapters on case studies illustrating the use of "*Agricultural physics*" (Chap. IV.7) and "*Agricultural chemistry*" (Chap. IV.8). The first very well shows the practical advantages of even a very simplified quantitative physical approach. From physically expressing the basic greenhouse mechanisms, the main outlines of greenhouse climate can be understood. In real greenhouses, outdoor conditions can be very dynamic. Then the basic greenhouse mechanisms can be extended to the separate physical processes acting in the interaction between the outside conditions and the greenhouse climate for a greenhouse with defined physical properties. In this way computer simulation enables the calculation of dynamic greenhouse climate, which can be applied for year round analyses of greenhouse systems behaviour.

Linked with crop modeling it can also predict greenhouse crop production. Besides the interest in the dynamics of greenhouse climate, also the spatial distribution can be of importance. Inhomogeneous temperature distribution causes inhomogeneous production. Moreover, at cold spots condensation on parts of the crop may increase risk for the development of fungi. Also ventilation might be inhomogeneous due to local differences in the driving pressure distribution. To study greenhouse climate distribution, computational fluid dynamics (CFD) proved to be a powerful tool now applied worldwide.

Chapter IV.8 deals with "*Agricultural chemistry in agrometeorology: relations with groundwater contamination*". Agrochemistry and soil chemistry have from the beginning been considered a part of agronomy; soil water matters particularly a part of (agricultural) physics. Together they stand at the basis of groundwater studies, as they largely consider the quantity and quality of groundwater recharge. The pressure of agricultural practices on groundwater resources is well-documented.

This chapter aims to provide some examples of problems that arise, after which mitigation strategies are discussed. Such strategies largely involve agrometeorology through attempts to optimize the use of fertilizers, pesticides and water for irrigation, three ingredients that are fundamental in order to satisfy the required increase of food production. The challenge is to increase the production without further degradation of water resources.

The most documented consequences of agricultural activities around the world concern (i) groundwater salinization; (ii) nitrate contamination; and (iii) pesticide contamination. Groundwater salinization is mainly linked to two phenomena: (a) crop transpiration and soil evaporation, further enhanced by high groundwater levels, irrigation and groundwater recycling and (b) seawater intrusion due to overexploitation in coastal areas. Fertilization is the principal source of nitrate contamination on a regional scale. Groundwater contamination by pesticides can result from their leaching after application due to subsequent rainfall or from inappropriate disposal methods.

Moreover, there is often a great lack of technical support for farmers with regard to the application of mitigation measures. Here lies one of the major problems of the application of agro-environmental policies. Farmers are often considered largely responsible for nitrate pollution and pesticide pollution, but are frequently not fully aware of the consequences of their practices or lack the knowledge to improve them. In other cases, they lack the economic capacity or will to change the situation. Imposing rigorous measures and applying fines in the case of non-compliance is not the solution and has rarely proven to be successful, also because the control is often deficient or even nonexistent. Instead, communication and cooperation with the farmers, as well as technical support and training, are key measures for a wide adoption of agro-environmental policies.

Then we reach the third component (type of contents) of the C-domain, that of "*Education, training and extension*", dealt with in Chap. IV.5. While the scientific principles are the same in all countries, the potential applications and the conditions under which they have to be used vary greatly between countries in different climates and at different stages of development. Hence this also applies to education, training and extension to put them into effect. Training programs at all levels must therefore be adapted to national and regional needs. In recent operational developments this includes developing extension agrometeorology around the establishment of agrometeorological services, particularly in non-industrialized countries.

Institutionally, this demands new educational commitments, on a large scale, by the providers of the products as well as by governments/NGOs; to renew the agricultural extension in approach and contents, both with strong participation of farmer groups that will come to the Climate Field Schools/Farmer Field Schools, for new and improved needs assessments. A most important conclusion is the need for local networking and national networking that should precede and follow such educational commitments.

In addition to the follow-up of the training facilities themselves, this is the second institutionalization without which upscaling of successes will be much more difficult to reach. Illiteracy, vulnerability, poverty and a high need for farmer differentiation are initial and boundary conditions of this new approach in educational commitments. External funding promised to Africa and internal funding promised by governments of giants like China, India and Brazil, but also by small countries like Malawi and Mali, should, among many other priorities, be used also on such institutionalized commitments.

The final type of contents of the C-domain has to do with "policies". The first chapter of that category of contents is the Chap. IV.12 on "*Climate prediction and weather forecasting*". It argues that the challenges of making predictions that are relevant to agricultural decision makers is to give them timely, salient information that links the knowledge accrual processes of the scientific supply side to the demand of decision makers. Designing research endeavors that can accomplish this is difficult because: (i) Predictions, even when accurate, often fall in the wrong timeframe, or lack needed specificity. (ii) The uncertainties inherent in prediction may not be made apparent to those using the predictions. (iii) Science policy makers often misconstrue the context of application. Evidence of the first two points is available in the case of climate models.

Part of the reason for this problem, and for many problems in the prioritization and execution of public science, is that the views of the people who are supposed to be benefiting from the science are not fully taken into account. Much of the policy that drives predictive science in the US is the result of political decisions made at the national level, like Presidential directives. In the US, long term climate prediction is not "on the radar" for many farmers, since it is not tied to production issues. But if it is going forward anyway, science decision makers are obviously not fully or accurately accounting for the context in which the science will find use. Investigating the whole policy context, including the expectations set by policy makers and the potential for the prediction to have sufficient skill, along with user needs, is important to gain a comprehensive view of how supply of science might match demand.

Of course central in the aspects of "policies" is the Chap. IV.13 giving "*Examples of agrometeorological decision support developed and used in South America*". Great climatic differences in South America favor the agricultural development and exploration of numerous vegetative species, such as in the Amazon rainforest, subsystem cultures, great commodities as soybeans, corn, coffee, and sugarcane, and regional adaptations ranging from temperate climate to tropical species. Therefore, it should be a policy that agrometeorological decision support for agrometeorological services and information under development or to be implemented should address the different regional threats. An account is given of numerous examples in many countries of the area. Although all countries have reasonably good NMHSs, some agrometeorology or agrometeorological decision support products do not receive their due recognition.

An example of a product that has been developed in Brazil, which clustered several institutions in various Brazilian states and even South America countries such as Columbia and Costa Rica, among others. Agrometeorological Monitoring Systems (SMAs) inform the farmer of weather conditions and their influence on crop development and productivity. The SMAs supply information about weather conditions and whether they are favorable to the development of each phenological phase of coffee. Given the aspects presented and described in this chapter, it is clear that although agrometeorology is of high interest in decision support for sustainable development of agriculture in South America, and relevant to food production programs, there is a lack of direct agrometeorological services and information that is immediately useful to and easily accessible by farmers and consultants. The process of training and improving the resilience of farmers and technical personnel should therefore also be a priority.

Chapters IV.14, IV.15 and IV.16 deal with policies of "*Greenhouse gas mitigation in agriculture*", a field that is dealt with from three points of view: "*Global potential; Strategies and economics; and Supporting evidence*". The total GHG emission from agriculture was estimated to increase by about 50% from 2000 to 2030. Early in this period, agricultural expansion was by far the leading cause at a global scale, whether through forest conversion for permanent cropping, cattle ranching, shifting cultivation or colonization agriculture. Most prominent underlying causes of deforestation and degradation are economic factors, weak institutions and inadequate national policies. Mitigation techniques such as improved feed quality, improved manure management, improved fertilizer use and greater applied nitrogen efficiency, and improved water management in rice paddies all have to be considered in order to minimize the impact of agriculture on climate.

The agricultural sector was once a major contributor to GHG emissions, but it has been superseded by the energy and transportation sectors. However, all sectors have a role to play and all must be mobilized in the collective efforts to mitigate global climate change. Significantly, agriculture has an important role because of the large land areas involved, and because there are already many available technologies and opportunities in agriculture to contribute to the global mitigation effort, many of which can be implemented with minimal or no cost. Soil carbon sequestration has a higher mitigation potential than emission reductions in agriculture, although both are important. These are best achieved under management systems with higher carbon density, as well as improved soil conservation.

Also, enhanced soil carbon pools provide numerous agronomic and environmental benefits, and stabilize global nutrient cycles, with the resultant long-term enhancement of the resilience of agricultural systems to climate change. There are lingering uncertainties on the permanence of the sequestered carbon and on the potentials for carbon leakage, but permanence can be assured by promoting land management philosophies such as sustainable land management that enhance economic viability while also sequestering carbon. It can also be assured through agronomic practices that "inject" more carbon at depth, using more deep rooting cultivars.

The lack of an effective carbon price is currently one of the most significant detriments to collective global action. There are some strong trends in the expansion of global carbon trading, and some initiatives to promote carbon taxes. These are positive, since ultimately they will promote a realistic price on carbon. However, some key constraints still need to be overcome, namely how to mobilize the large and highly diverse global farm populations, and how to certify sequestered carbon and GHG emission reductions, given the high variability inherent in agricultural production environments.

Clean Development Mechanism (CDM) rules should encourage the participation of small farmers and community forest and agroforestry producers, and protect them against major livelihood risks, while still meeting investor needs and rigorously ensured carbon off-set goals. Agroforestry, assisted natural regeneration, forest rehabilitation, forest gardens, and improved forest fallow projects should all be eligible under CDM, because they offer low-cost approaches to carbon sequestration, while offering fewer social risks and significant community and biodiversity benefits. Short-duration tree growing activities should be permitted, with suitable discounting. Unfairly favoring large plantations should be avoided. The successful promotion of livelihood enhancing CDM sequestration projects will require investment in capacity-building and advisory services for potential investors, project designers and managers, national policy makers, and leaders of local organizations and federations.

In Chap. IV.3, giving "*A basic view on models of nature and the concept of "sustainability"*", the policy discussion is primarily connected to the challenge of agricultural crop production in western and northern Europe, but the ideas are of a general character and could therefore be extended outside this geographical area. The authors believe that strategic thinking and strategic decisions on agriculture and the way of preparing tactical decisions have to be reconsidered everywhere. Elements of a strategy for future agricultural production systems are outlined by first looking at the concept of "sustainability", subsequently discussing economy, then presenting the concept of "globalization", and further taking a look at the general content of numerical models of nature and quantitative indices describing phenomena of nature. In the end they try to answer the following question: "*is it possible to attain sustainability by using numerical indices for navigation?*".

The term "globalization" is currently used to tell us that the world is developing into one complex society in the economical, financial, technological, political, social, and cultural sense. The term is most often used by the economists in the economical sense, and the economies in the world are interrelated through trade, production, unintended migration, tourism, and communication. Problems of "globalization" are connected to fragmentation of responsibility and lack of care for the totality. John Meynard Keynes is cited: "I sympathize therefore with those who would minimize rather than those who would maximize economic entanglement between nations. Ideas, knowledge, art, travel – these are the things which should of their nature be international. But let goods be homespun whenever it is reasonably and conveniently possible, and above all let the finance be primarily national."

Exchange of information is today easily performed by using internet on all levels. Information then can be distributed and used and exchanged both horizontally on the same level of responsibility and vertically between levels of responsibility discussed. But the contents of internet should no longer be as if we should construct a global village top-down, but they should become supportive of the bottom-up local and regional organizational approach, as a matter of policy.

Chap. IV.4 on "*Expert systems*" starts with arguing that, among others in Africa, developing coping mechanisms for climate variability was and is the logical first step in dealing with climate change. Response farming is the best known indigenous coping mechanism that in the course of time did get scientific recognition and support. Many traditional expert systems are still in place to this end but many are also loosing their efficiency due to climate and other changes.

Farming systems develop highly-relevant, but perhaps not-so-accurate, expert information systems. These are often in the form of proverbs, such as "Uttara chusi, yattara gampa" ("Wait for rainfall during September 13–26; if it fails, leave the place"), from south India. This proverb was tested against a crop model as a form of predicting crop failure. The model was found to be better at simulating the three lowest-yielding years than the proverb. However, this analysis contrasts formal and local expert knowledge, using the constructs of science (empirical measurement of yield and rainfall, simulation models) rather than those of society (livelihoods, income). In other words, such a comparison does not prove that a model is more *useful* than a proverb; merely that it is more accurate for a given metric of crop productivity, using a given dataset.

What insight does a needs-driven perspective give into the appropriate types of crop models and their use? The more complex models simulate processes that may explain the root cause of observed phenomena – for example declining yields due to poor nutrient cycling. In theory this can inform farmers how much fertiliser to apply; in practice, the majority of farmers will not be able nor willing to use such systems. Similarly to climate forecasts, there may be organisations better-suited to use such information. The benefit of these modeling systems may come through "discussion support" rather than decision support. However, client appropriateness and user friendliness of these products are conditions that should be fulfilled by specially trained intermediaries working with the providers of such types of information. Otherwise there remains still a big chance that farmer needs and farmer priorities are not met but solutions found are still in search of problems to be solved. A similar argument can be applied to yield forecasting systems.

Finally for the policy matters, in Chap. IV.2 on "*Ethics and policies*" the believe is expressed that ethics, such as the choice for a "farmer first" paradigm, should come first, then policies should be derived in accordance with these ethics and then science should come with research and application choices supporting the policies. Why does it almost nowhere work like that? If ethics are the moral principles governing or influencing our conduct, why are actually internal ethics of conduct in science discussed more than external ethics by scientists themselves?

Research priorities and research agendas incorporate values of what is seen by research managers as worthwhile. Research priorities and research agendas determine the future of research by selecting scientific and technological pathways that often cannot easily be changed. Even in the selection of materials and methods and the products of sciences are values incorporated, especially as they relate to the impact on society. In general, the research priorities of scientists are now criticized by many and often it is these days expected of science to reduce the gap between poor and rich countries.

In developing countries and countries in transition, responsibility to help poor farmers help themselves should, as a matter of policy, be with governments first. Government and NGOs can, however, work complementary. Governments must be able to leave certain interests to those concerned, organized in/by NGOs. The lessons learned point towards a need to, by all means, bridge the gaps towards the livelihoods of farmers. The reality shows that almost all products developed with focused scientific support are just the seeds sown for the development of actual agrometeorological services in an extension approach. We want to get to a situation in which, in a farmer first paradigm, livelihood problems and farmer decision making needs can guide the bottom-up design of actual services.

References

Baradas MW (1983) Solve agroclimatic constraints in the humid tropics at the ground. In: CAgM Report 18, WMO, Geneva, 16pp

NOAA (2009) Climate program office. Explaining climate to improve predictions. USDC/NOAA/OOAR, Silver Spring. http//www.cpo.noaa.gov/

Stigter K, Baier W, Barrie I, Brunini O, Dommermuth H, Gat Z, Gommes R, Keane T, Chan Ah Kee, Lomas J, Milford J, Ravelo A, Rijks D, Samui RP, Walker S, Wang Shili, Weiss A (2010) General. Chapter 1 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Zwiers FW, Zhang X (2003) Toward regional-scale climate change detection. J Clim 16:793–797

Zwiers F, Cattle H, Peterson TC, Mokssit A (2003) Detecting climate change. WMO Bull 52: 237–242

IV.2 Ethics and Policies

Kees Stigter

Early 2009 I got the invitation to deliver in the summer in Madison, Wisconsin (USA), a paper at a conference on "Sustaining soil productivity in response to global climate change: science, policy and ethics". I decided to talk about "Rural response to climate change in poor countries: ethics, policies and scientific support systems in their agricultural environments" (Stigter 2009a).

I purposely changed the positions of "ethics" and "science" in the sequence, because I strongly believe that ethics, such as the choice for a "farmer first" paradigm (see below), should come first, then policies should be derived in accordance with these ethics and then science should come with research choices and application choices supporting the policies. Why does it almost nowhere work like that? If ethics are the moral principles governing or influencing our conduct, why are actually internal ethics of conduct in science discussed more than external ethics by scientists themselves? [See also Box IV.1]

More recently, change can be noted. Korthals (2008) indicates that since the Second World War researchers have been increasingly confronted with a range of ethical problems and ethical dilemmas. He states that it is often said that science is objective and ethics, which is linked to personal choices, is subjective, but that a closer look makes it clear that there are ethical values which must be adopted in the pursuit of science. Korthals (2008) argues that one can distinguish between the ethics of research priorities, of doing research (experimenting), of making the results public and of patenting.

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_102,

Box IV.1

The following is taken from Fossey (2008). Today many large corporations, undertaking pioneering research, contribute to a large body of agricultural inventions. However, the implementation of these technologies has met with considerable controversy and concern to many people across the world. Not only are the views and opinions conflicting at a scientific level, but also in terms of ethical issues and moral issues surrounding their use. Ethical issues are of particular interest with respect to genetic engineering and animal cloning.

Others ask more policy oriented ethical questions: What specifically are the consequences of biotechnology research, development, and deployment? A pertinent question is: Will this technology and others being developed e.g. nanotechnology be able to revolutionise farming, save the environment and be profitable especially at the level of small farms; and thus address the humanitarian, environmental and business ethics simultaneously? In the field of ethics, moral standards that govern the appropriate conduct for an individual or group of individuals are termed bioethics, and can be defined as: "a method, procedure, or perspective, or norms of conduct that distinguishes between acceptable and unacceptable, right or wrong, behaviour". The four fundamental principles of bioethics include:

- beneficence, which refers to the practice of good deeds;
- non-maleficence, which emphasizes an obligation to not inflict harm;
- autonomy, which recognises the human capacity for self-determination and independency in decision making; and
- justice, which is based on the conception of fair treatment and equity through reasonable resolution of disputes.

Research ethics can be described in terms of ethics of the topics and findings (morality) and secondly as ethics of method and process (integrity). Institutions that practice research have adopted professional codes relating to research ethics that all include principles of honesty, objectivity, integrity, confidentiality, carefulness, openness, competence, respect for intellectual property, responsible publication, responsible mentoring, respect for colleagues, social responsibility, non-discrimination, legality and animal care. Objectivity in research gives researchers trustworthiness. This applies to both the a priori tasks of setting up the research and gathering the data and in the posteriori tasks of interpreting and publishing the results. [These are all what I call internal ethics. KS.]

Externally, research is rather directed towards crops, traits and technologies that will be of benefit to developed industrialized countries or commercial farms that can guarantee adequate returns on investment. This has met with much concern. In developing countries, with high poverty levels, the impacts of these technologies are yet to be demonstrated as they have so far performed below expectations. Although it is probably true that genetic engineering could produce numerous improved varieties, its potential role in abolishing malnutrition and in improving yields and livelihoods in developing countries is still being questioned and could ultimately jeopardize the sustainability of small-scale and rural farmers, whom are mostly the conservators of land races, adapted over thousands of years to local environments.

As most of us subscribe to "utilitarian ethics" [These are what I call external ethics. KS.] as scientists, we must judge according to the outcome of our actions. If our actions [These are what I call "choices for and carrying out of research policies". KS.] are for the greatest good, or for the largest number of people, then the action is deemed acceptable. It is the responsibility of all of us to ensure that agricultural research, private or public, does enhance agricultural performance and that it serves the broader society now, and in the future, in a sustainable manner (Fossey 2008).

In all cases conflicting interests, norms and values are at stake, which require ethical reflection. Scientists struggle with the ethical acceptability of the relationship between private and public research and their combination; they question the patenting systems. Moreover, it became clear that also in science, fraud and careerist individuals could distort the trust normally people have in science. Controversies which arise over research, like on genetic modification, or accepting research funding from certain organizations which have vested interests in the outcomes, attract the attention of policy makers and civil society alike. Very often research for e.g. crops is done of which the results can only be used by large international companies and not by small crop holders. Here is the notion of fair and equitable justice at stake (Korthals 2008).

Research priorities and research agendas incorporate values of what is seen by research managers as worthwhile. Research priorities and research agendas determine the future of research by selecting scientific and technological pathways that often cannot easily be changed. Even in the selection of materials and methods and the products of sciences are values incorporated, especially as they relate to the impact on society.

In general, the research priorities of scientists are now criticized by many and often it is these days expected of science to reduce the gap between poor and rich countries (Korthals 2008). This having been said, what is the situation in agrometeorology? Part I of this book shows how choices made in applied agrometeorology can lead us to agrometeorological services. Section IV.5 talks about the institutionalization of extension training with which such services can be established and validated (Stigter 2009b). Let's see a bit of history (see also Stigter 2006).

The Technical Commission for Agricultural Meteorology (CAgM) of the World Meteorological Organization (WMO), in its session in Havana in 1995, talked about "strengthening members' indigenous capabilities to provide relevant meteorological services to agriculture and other related sectors" (WMO 2006). It was a CAgM Workshop in Ghana in 1999 that started to distinguish agrometeorological services and their four support systems: data, research, education/training/extension, policies (Stigter et al. 2000). In the present decade we have understood that the mentioned scientific support systems may drive the action support systems needed, these days very often the most urgent ones for mitigating impacts of disasters such as high intensity rainfall and floods; tropical storms, tornadoes and strong winds; extreme temperatures including heat waves and cold waves; droughts and wildfires and bush-fires (e.g. Rathore and Stigter 2007).

But the resulting applied agrometeorology is no science supported extension agrometeorology, where it should be all about decisions and action (Stigter 2009b). It seldom reaches the livelihoods of farmers in developing countries, with their majority of peasants with low degrees of formal education and low communication infrastructure and organizational infrastructures (Stigter et al. 2007). In this context we should realize that climate change, with its increasing climate variability and its higher frequency of extreme events in countries where many people and regional food security still depend on local agriculture, makes the necessity of actual agrometeorological services with extension products only more urgent. But what should be the approach? [See also Box IV.2].

Box IV.2

Agrometeorological (Advisory) Services (A(A)Ss) will, as a matter of policies, be best part of the National Meteorological and Hydrological Services (NMHSs) but agrometeorological services as products may also be generated by (Extension Sections of) Agricultural Research Institutes and Universities. Such Extension Sections may in the course of time be called "Services Departments". Coordination must be organized in strong collaboration with A(A)Ss.

One always will have to deal with such organizational and institutional details but we may say already here that A(A)Ss should be organized as close to the farmers as possible, the way this is done in India as described below with respect to disasters (Stigter 2008a). One important reason for this is that many agrometeorological services will have to do with coping with disasters (Murthy and Stigter 2003).

In India effective and accountable local authorities are considered the single most important institution for reducing the toll of natural and human induced disasters (Sahni and Ariyabandu 2003). The country's day to day administration is around the District Collector who is also in charge of all the relief measures at that level. There are sub-divisions and tehsils. The lowest unit of administration is the village. All these tiers function as a team to provide succour to the people in the event of disaster. It would be very helpful if indeed establishment of agrometeorological services could be guided at the lowest administrative level (Stigter 2008a).

In China we identified at the provincial and related sub-provincial and county levels, in Inner Mongolia Autonomous Region, services related to crop planning and variety planning as well as on spring wheat sowing advices in melting frozen soils.

In Ningxia Autonomous Region, such services were about improving microclimate for water melon in a dry mountainous area and fungus disease forecasting in wolfberries.

In Jiangxi Province, planning the growing of navel oranges and their protection was dealt with, together with relay cropping of late rice into lotus.

In Henan Province, services dealt with more accurate determination of water saving supplementary irrigation of wheat and the forecasting of peony flowering for commercial activities.

While in Hebei Province winter straw mulching of wheat and early warning of less sunshine and related low temperatures for winter vegetables in simple but very popular plastic greenhouses were the subjects for agrometeorological services (Stigter 2009a).

All these examples have been institutionalized by the provincial meteorological administrations concerned. Several of these agrometeorological services have locally had recent scientific support but others are in high need of much more supportive research. Institutionalization as well as research support should be matters of provincial and central government policies. See also Part II of this book.

Socialization of agrometeorology means that policy matters of farmer oriented action support systems, policy support options and capacity building strategies should get attention (Stigter 2008a). Opportunities for agrometeorological services to farmers should be the guiding principle (Murthy and Stigter 2006).

Analysis of the current state of affairs in agriculture shows that the adverse effects of nature can be handled, that efforts to develop and apply technology for intensification in a variety of farming systems are under way, but that sustained adoption by the mass of smallholder farmers has not sufficiently taken place (Kuyvenhoven 2008). See also Gommes (2003), Sachs (2005) and Stigter (2008b).

In developing countries, public services providers (among intermediaries) can for example package crop disease warning systems as products of research into formats that fit farmers' needs, while the latter provide feedback, for systems that are sufficiently valuable and user friendly, for improvements, to intermediaries, of whom some are researchers. Policies can establish such communications. Reliability of weather data inputs is the backbone for sustainability of such schemes. The last conclusions are from work on crop disease warning systems (Gleason et al. 2008).

Already 20 years ago, Chambers (1990) stated that the transfer of technology paradigm has been increasingly questioned, even in the citadels of normal professionalism. Reductionist research, high input packages and top-down extension have had their successes. In the uniform and controlled conditions of industrial and Green Revolution agriculture they have raised output per unit of land. But the sustainability of that increase remains open to question and the transfer of technology does not work well with the more complex, diverse and risk-prone rainfed agriculture of much of the poorer South (Chambers 1990), including multiple cropping as an approach to these problems (Baldy and Stigter 1997).

Explanations of non-adoption of technologies are for more than two decades now increasingly sought in the technology itself, the concept of package and the process whereby the technology is generated (Stigter 2008a). In Sect. III.5.2.(i), agroforestry was shown to be such a case of low adoption that could be improved by an improved capacity building approach (Casey 2004). A Green Revolution for the poor is in need of other science and other education and extension (KNMI 2009). Policies have to guide this paradigm change.

In developing countries and countries in transition, responsibility to help poor farmers help themselves should, as a matter of policy, be with governments first. Government and NGOs can, however, work complementary. Governments must be able to leave certain interests to those concerned, organized in/by NGOs. The lessons learned point towards a need to, by all means, bridge the gaps towards the livelihoods of farmers (Stigter 2008c). The reality shows that almost all products developed with focused scientific support are just the seeds sown for the development of actual agrometeorological services in an extension approach (Stigter 2009b).

We want to get to a situation in which, in a farmer first paradigm (e.g. Chambers et al. 1989; Winarto 2007), livelihood problems and farmer decision making needs can guide the bottom-up design of actual services. Services based on products generated by operational support systems in which understanding of farmer livelihood conditions and innovations have been used (Stigter 2008c).

We have obtained in the last decade quite a good idea of what should be done to develop such agrometeorological services from scientific products generated by National Meteorological and Hydrological Services (NMHSs), Agricultural Research Institutes and Universities (Stigter 2005; Stigter 2008b; KNMI 2009). But what we need is a policy of institutionalization of science supported establishment and validation of such agrometeorological services (Stigter 2009b). Capacity building in that direction is the most needed policy of all. See also Sects. II.A, B, and D and Chap. IV.5.

References

Baldy C, Stigter CJ (1997) Agrometeorology of multiple cropping in warm climates. Translated from the French (with an Epilogue for the English version). INRA, Paris; Oxford & IBH Publishing Co., New Delhi; Science Publishing Inc., Enfield, 237pp

Casey JF (2004) Agroforestry adoption in Mexico: using Keynes to better understand farmer decision-making. J Post Keynes Econ 26:505–521

Chambers R (1990) Microenvironments unobserved. IIED Gatekeeper Series No. 22. International Institute for Environment and Development, London, 15pp

Chambers R, Pacey A, Thrupp LA (eds) (1989) Farmer first: farmer innovation and agricultural research. Intermediate Technology Publications, London, 243pp

Fossey A (2008) Research ethics and agricultural innovations. (CTA. Knowledge for development). http://knowledge.cta.int/en/Dossiers/S-T-Issues-in-Perspective/Science-and-ethics/Articles

Gommes R (2003) Agrometeorological policy between necessity and fashion. Eur Soc Agron Newsl 25, 4pp

Gleason ML, Duttweiler KB, Batzer JC, Taylor SE, Sentelhas PC, Monteiro JEBA, Gillespie TJ (2008) Obtaining weather data for input to crop disease-warning systems: leaf wetness duration as a case study. Sci Agric (Piracicaba, Brazil) (special issue):76–87. http://www.scielo.br/scielo.php?pid=S0103-90162008000700013&script=sci_arttext

Korthals M (2008) Ethics in science for development. (CTA. Knowledge for development). http://knowledge.cta.int/en/Dossiers/S-T-Issues-in-Perspective/Science-and-ethics/Articles

KNMI (for Netherlands Government, compiled by Kees Stigter, second update, 2009) Capacity building in the area of agrometeorological services through roving seminars. Document originally distributed and presented as CAgM-XIV/INF.4 at the XIVth Session of the WMO CAgM, New Delhi, October/November 2006, 19pp

Kuyvenhoven A (2008) Africa, agriculture, aid. NJAS (Wageningen Life Sci J) 55:93–112

Murthy VRK, Stigter CJ (2003) Stigter's diagnostic conceptual framework for generation and transfer of agricultural meteorological services and information for end users. In: Agrometeorology in the new millennium – perspectives and challenges. Proceedings of the 2nd National Seminar of the Association of Agrometeorologists in India, Ludhiana, 9pp

Murthy VRK, Stigter CJ (2006) Operational agrometeorological services for extension needs and the supportive role of agricultural research. In: Strengthening operational agrometeorological services at the National level. Proceedings of a Regional Meeting, Manila, 2004. AGM-9, WMO/TD-No. 1277, WMO, Geneva, pp 199–208. [Also available on-line at the WMO/CAgM website]

Rathore LS, Stigter CJ (2007) Challenges to coping strategies with agrometeorological risks and uncertainties in Asian regions. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 53–69

Sachs J (2005) The end of poverty. Economic possibilities for our time. Allen Lane, London, 396pp

Sahni P, Ariyabandu MM (2003) Disaster risk reduction in South Asia. Prentice-Hall of India, New Delhi, 370pp

Stigter K (CJ) (2005) Building stones of agrometeorological services: adaptation strategies based on farmer innovations, functionally selected contemporary science and understanding of prevailing policy environments. Opening Key Note Lecture at the FPEC Symposium, Fukuoka. J Agric Meteorol (Japan) 60:525–528

Stigter K (2006) A contemporary history of a new approach to applied agrometeorology. Available at the INSAM website (www.agrometeorology.org) under "History of Agrometeorology" of 6 February

Stigter K (2008a) Policy support for capacity building in weather and climate services focused on agriculture. J Agrometeorol 10(2):107–112

Stigter CJ (2008b) Agrometeorology from science to extension: assessment of needs and provision of services. Invited lecture at the 50th anniversary of the Chinese Academy of Agricultural Sciences, Beijing. Agric Ecosyst Environ 126:153–157

Stigter K (2008c) Agrometeorological services under a changing climate: old wine in new bags. WMO Bull 57:114–117

Stigter K (2009a) Rural response to climate change in poor countries: ethics, policies and scientific support systems in their agricultural environments. Paper Presented at the Conference "Sustaining Soil productivity in Response to Global Climate Change: Science, Policy and Ethics", Madison. Draft available at the INSAM website (www.agrometeorology.org) under "New information for agrometeorologists" of July.

Stigter K (2009b) Scientific support to the establishment and validation of agrometeorological services. SciTopics, Elsevier. Research summaries by experts. Agricultural and Biological Sciences (Miscellaneous). http://www.scitopics.com/categories.jsp?domain=1100

Stigter CJ, Sivakumar MVK, Rijks DA (2000) Agrometeorology in the 21st century: workshop summary and recommendations on needs and perspectives. Agric For Meteorol 103:209–227

Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi YM (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha RP (eds) Managing weather and climate risks in agriculture. Springer, New York, pp 171–190

Winarto YT (2007) "Bull" versus "Tiger": can the "Bull" and the "Tiger" work collaboratively? A reflection of "Farmer First" in Indonesia. Presented in Farmer First Revisited: A Workshop on Farmer Innovation and Agricultural Research and Development Twenty Years on". Institute of Development Studies, University of Sussex, Brighton, December. http://www.future-agricultures.org/farmerfirst/files/T2b_Winarto.pdf

WMO (2006) Commission for Agricultural Meteorology (CAgM). The first fifty years. WMO 999, Geneva, 44pp

IV.3 A Basic View on Models of Nature and the Concept of "Sustainability"

Tor Håkon Sivertsen and Janis Gailis

The discussion below is primarily connected to the challenge of agricultural crop production in western and northern Europe by the global change of climate (Box IV.3), but the ideas are of a general character and could therefore be extended outside this geographical area. We believe that strategic thinking and strategic decisions on agriculture and the way of preparing tactical decisions have to be reconsidered everywhere.

Elements of a strategy for future agricultural production systems are outlined below by first looking at the concept of "sustainability", subsequently discussing economy, then presenting the concept of "globalization", and further take a look at the general content of numerical models of nature and quantitative indices describing phenomena of nature. In the end we try to answer the following question: *is it possible to attain sustainability by using numerical indices for navigation?*

Box IV.3

The climate of the earth has been strongly influenced by human impact in at least the last 100 years. Examples of human impacts on climate are: (i) heavy outputs of green house gases into the atmosphere, (ii) destruction and replacement of vast areas of forest – these days especially in the tropics – and (iii) overgrazing by cattle in areas like the Sahel region south of Sahara. The societies and the agriculture of Europe are now seriously challenged by the global change of climate. What will be the outcome for different regions of Europe is not clear in detail, but according to scenarios of future climate, warmer weather and climate will be more violent, with serious periods of drought, and the frequency of natural disasters connected to such weather will increase (e.g. Benestad 2005; Sivakumar 2005; Stigter 2008). See also various sections of Part III of this book.

T.H. Sivertsen (✉)
Norwegian Institute for Agricultural and Environmental Research, Aas, Norway
e-mail: tor.sivertsen@bioforsk.no

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_103,

The Bruntland Commission of the United Nations did define “sustainable development” as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (United Nations 1987). Sustainability then relates to the continuity of economic, social, institutional and environmental aspects of human society as well as to the non-human environment.

Sustainable development is connected to the ways institutions in human societies are organized and interrelated; and to the ways people act as individuals and members of institutions in their actor networks (Latour 2005). Because agricultural production is basic primary production of food and fiber, a sustainable agriculture must be attained in order to have sustainable development in a society. We will define sustainable agriculture in this manner: People should organize agricultural production in such a way that they can feed themselves properly, and deliver the agricultural production systems and the surrounding environment to the next generations in a shape making it possible to feed themselves properly.

The etymological meaning of the word “economy” can be traced back to an ancient Greek word meaning “one who manages the household”, that is administration of a household. In modern days we think of money when we use this word, because we are always exchanging money when engaged in production, distribution, and consumption of goods and services. We also give value in money to agricultural land, to the environment (although often forgotten when communal), to our houses and other buildings and constructions.

Money is not a real thing, but merely an elegant, derived universal way of exchanging goods, services, equipment, land and constructions at some market (or in the society). When making strategic decisions like use of land and how to organize production and trade, the most important index/parameter used is often the value in money of the outcome of the decision. In order to have a sustainable development and sustainable agriculture in a country or a region, it is of importance to have an economical system putting the money concept in the right place (e.g. Schumacher 1999; Daly 2007). On every level in a society, money must have the right place when making decisions. Very generally one could think of several levels of economy. The responsibility in the economical sense of an organization at a certain level being connected to what is determined at the lower levels, and what is happening at higher levels. But it should not be dependent on similar organizations at the same level at other places in the world.

The dynamics of the current economy of the world is connected to investments, and making profit of the investments. This is a top-down way of acting and it often destroys the environment, and future possibilities of using the resources originally available. But one could think of a bottom- up approach instead, starting with organizing the producing units at the lowest level, and the lowest level should then determine the next level.

In the European Union the common strategy for organizing agricultural production is called Common Agricultural Policy (CAP). We characterize the current policy as a top-down policy, very strongly emphasising regulations. Large enterprises seem to be favoured by the system, though this is not explicitly an aim. A basic criticism of CAP must be that it is causing environmental problems, it hurts small scale agriculture and commerce, and it also generates artificially high food prices. From a sustainability point of view, developing smaller scale economies, including farming, could be given a try inside the European Union.

Powerful tools for describing, understanding and modeling phenomena of nature are the scientific methods of the natural sciences. In physics it is often referred to as the hypothetico-deductive principle. Such general methods (the scientific principle) used in (agro)meteorology were interpreted by Sivertsen (2005, 2006a) as systems for classification of natural phenomena and for describing the phenomena by defining parameters and by attaching quantitative measurable parameter values to the phenomena (Fig. IV.1, Eitzinger et al. 2008). Furthermore the methods contain basic mathematical equations connecting the parameters, and the most universally valid equations are often called "laws of nature". These "laws of nature" are often simplified, and empirical and semi-empirical parameters are added and connected to the systems when specific phenomena are studied. The following "laws of nature" are often used in meteorological models: conservation of energy, conservation of mass, conservation of momentum, and the second law of thermodynamics.

The testing of the systems by comparing the model results to independently measured parameter values was interpreted by Sivertsen (2006b) as determining the temporal and spatial scope of the methods on five levels, the level of classification of nature, the level describing the phenomena by attaching measurable quantities/parameters, the level of the "laws of nature", the level of the simplified and empirical equations, and the level of the validity of the input parameter values (containing representativeness of the parameters and correctness of the measurements). In practice these methods are used for constructing weather prognoses on global, regional and local scales, for making scenarios of the climate of the future, for constructing crop growth models, and also agrometeorological models for giving warnings of attack of fungi and insects in orchards and crops.

The highest, basic levels contain in fact all phenomena of nature, possible to observe and possible to denote by giving them names – also compound phenomena like "drought" or "climate". But not all phenomena of nature are easily and completely described by attaching values of measurable parameters. Their development in time and space may not always be described by "laws of nature", like so many phenomena of physics and fluid dynamics. The methods are used to serve the two lowest levels for characterizing compound phenomena like "drought" by indices (e.g. Dunkel 2009; Škvarenina et al. 2009). Also other phenomena of the climate or caused by climate may be described by indices (e.g. Zhao et al. 2006; Eitzinger et al. 2008). By using "drought-indices" it is possible to give warnings to the farmers, and such indices are also used for decision support on national and regional levels (e.g. Dunkel 2009). There are a wealth of examples in Part III of this book.

Also different types of numerical indices are developed for characterizing "sustainability". But "sustainable development" and "sustainable agriculture" are

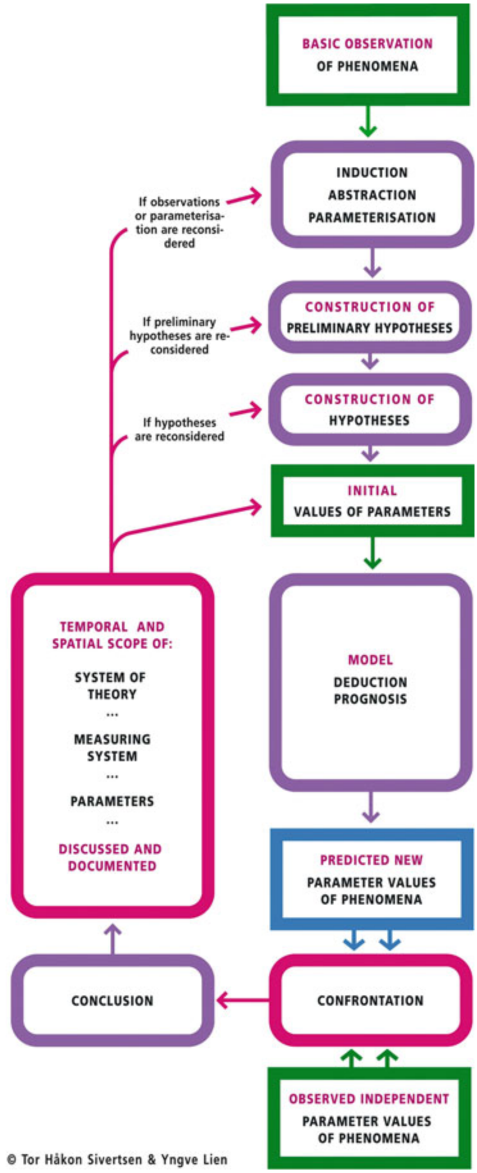


Fig. IV.1 A graphical representation of an interpretation of the scientific principle used in agro meteorology

not plain physical or biological phenomena. These concepts also are ethical characteristics of the development of very complex processes – the interaction of human societies with nature and the environment. Therefore, it is crucial to discuss the scope of these scientific methods when considering "sustainability" and "sustainable agriculture". By only using an index value as a characteristic and help for decisions, crucial factors connected to the complex processes giving this value may be hidden and not cared for. In the mood of Part I of this book, support systems are good intentions but without policies they will not lead to services that help farmers, their production systems as well as their societies.

The general ideas of sustainability presented above are not considered controversial, but in order to develop strategies also many technical details of farming systems, related institutions and the features of the surrounding society must be determined and tailored by practical research, testing and empirical trials.

We call the basic unit for agricultural production a farm; and we intend to present consistent characteristics of what could be developed into a sustainable system for farming. We define a farm as an institution for agricultural production containing fields for growth of field crops, grassland, houses and production equipment for farming of a size sufficient to produce enough food of a varied diet at least to support a family:

- Most of the food consumed by the people living on the farm should be produced on the farm.
- The farm should have a great degree of economic autonomy, and the farmer and his family should own the farm. An example is the traditional Norwegian system of allodial ownership (NOU 2003) but subsistence and near subsistence farming in developing countries are still widely existing examples.
- There should be developed a system for recycling of minerals and other non-renewable resources, both on the farm, and connected to the nearest community of the farm.
- There should exist a formal social system for handing the production system of the farm from one generation to the next generation.
- Sanity and order should be connected to the environment of the farm, including nearby lakes, fiords, ponds, small streams and other sources for fresh water, and ocean bays.
- Possibility for coping with extreme weather (preparedness) should be developed on this farm level.
- The consumption of energy at the farm and energy connected to production, transport and storage of goods should be based on local resources wherever possible.
- The treatment of wastes from the farm should take place in the vicinity of the farm wherever possible.

Sustainable agriculture cannot exist in a society lacking general sustainable features, and no sustainable society can exist without sustainable agriculture. We can think of developing some sort of system of institutions on different levels containing small farms on the lowest level, like a system of "Chinese boxes", while inside one box there may exist not only one box, but several equal boxes on the lower level. Each box should have a great degree of autonomy in the economical sense. The level of village can contain small entrepreneurs, small scale industrial production based on local resources, stores etc. Incidentally, contemporary Chinese villages were basically planned to work like this. The problem is that on a larger scale the units do not remain independent of each other.

At one higher level one can put the responsibility of production of machinery, maintenance and recycling and treatment of wastes of this machinery for all the lower levels. On this level one can have some production of commodities or production of equipment. There should be the responsibility for maintenance of the equipment, for the cycle of the products and wastes, for the exchange of energy and the use of energy on the lower levels, for the mineral chains, and the commodity chains on the lower levels. Each level should have a great amount of economical independency, but also responsibility in the economical and technical sense. The economic responsibility should be closely connected to production, distribution and consumption and to treatment of waste at this level. What is happening on the same level elsewhere in the world should not be crucial in the economical sense. This is quite different from the occurring globalization of financial systems and economies in the world (see below).

The so called Daly rules for sustainability for renewable and non-renewable resources as well as for pollution of soil and water (Womersley 2002), are implicitly contained in the rules given above for a farm, and they should also be contained at each level of such a system of "Chinese boxes" of responsibility. Implementation should start on the lowest level, finding out what could be implemented.

The term "globalization" is currently used to tell us that the world is developing into one complex society in the economical, financial, technological, political, social, and cultural sense. The term is most often used by the economists in the economical sense, and the economies in the world are interrelated through trade, production, unintended migration, tourism, and communication. Problems of "globalization" are connected to fragmentation of responsibility and lack of care for the totality – the climate and the environment for the present and future generations; and of course problems are connected to the antagonism between cultures and nations.

Daly (2007) is criticising globalization – big companies protecting their know how and knowledge and not respecting national and regional institutions' responsibility towards citizens and nature. He is citing the following passage of John Meynard Keynes:

> I sympathize therefore with those who would minimize rather than those who would maximize economic entanglement between nations. Ideas, knowledge, art, travel – these are the things which should of their nature be international. But let goods be homespun whenever it is reasonably and conveniently possible, and above all let the finance be primarily national.

Exchange of information is today easily performed by using internet both on the global level and on local and regional levels. Information then can be distributed and used and exchanged both horizontally on the same level of responsibility and vertically between levels of responsibility discussed above. But the contents of internet should no longer be as if we should construct a global village top-down, but they should become supportive of the bottom-up local and regional organizational approach.

It is possible to characterize physical, biological and agricultural phenomena by first giving each phenomenon a name and then attach numerical indices and values of quantitative parameters to the phenomenon. Indices have been used for making decisions in agronomy for many years. Again it should e noted that there are many examples in Part III of this book. This is a sort of navigating a compound system in time and space by quantitative modeling of the system. And of course such methods should also be used in the future when making decisions.

Notwithstanding the differences of sustainability from physical and biological phenomena mentioned earlier, several types of sustainability indices have also been developed. The Dow Jones Sustainability Index (DJSI) World is constructed to make it easier for institutional investors to choose socially and environmentally sustainable investments. In a press release on their website (www.sustainability-index.com/) we are told:

> The Dow Jones Sustainability Indexes follow a best-in-class approach and include sustainability leaders from each industry on a global level. The annual review of the DJSI family is based on a thorough analysis of corporate economic, environmental and social performance, assessing issues such as corporative governance, risk management, branding, climate change mitigation, supply chain standards and labor practices.

On another website (www.ciesin.columbia.edu/indicators/ESI/) we find a description of the 2008 Environmental Performance Index:

> The 2008 EPI provides policymakers and environmental experts an empirical grounded basis for comparing the environmental performance of nearly 150 countries worldwide. While general trends exist, such as a correlation between health and strong environmental health performance, some countries perform beyond income-based expectations. The results highlight policy leaders and laggards. They also provide a basis for identifying environmental "best practices".

Such indices may sometimes provide useful information, but we do not think it is possible to achieve sustainability by using such indices as instruments for navigation. They are at best a measure of some aspects of sustainability that are, however, connected to the livelihood of people at the bottom in undefined ways. We rather have recommended a sort of bottom up procedure economically and technically, starting with small scale farming at the bottom, and a small scale economy as the first step.

At higher levels the interconnections will be very different from the current globalization. The above thinking should be seen in the context of demands for more sustainable societies in need of different living patterns and consumption patterns in the widest sense, including energy and transport and including a different use of the (climatic) environment and different coping strategies with the expected changes (e.g. Senge et al. 2008). And the proof of the pudding is in the eating.

References

Benestad RE (2005) Climate change scenarios for northern Europe from multi-model IPCC AR4 climate simulations. Geophys Res Lett 32:L17704, 3pp. http://www.agu.org/pubs/crossref/2005/2005GL023401.shtml

Daly HE (2007) Ecological economics and sustainable development in 'Selected Essays of Herman Daly', Advances in Ecological Economy Series. Edward Elgar, Cheltenham, UK, etc, 288pp

Dunkel Z (2009) Brief surveying and discussing of drought indices used in agricultural meteorology. IDŐJÁRÁS, Proceedings from the Oscarsborg Symposium, June 2008, 113:23–37

Eitzinger J, Thaler S, Orlandini S, Nejedlik P, Kazandijev V, VuceticV, Sivertsen TH, Mihailovic DT, Lalic B, Tsiros E, Dalezios NR, Susnik A, Kersebaum KC, Holden NM, Matthews R (2008) Agroclimatic indices and simulation models. In: Nejedlik P, Orlandini S (eds), Survey of agroclimatic practices and applications in Europe regarding climate change impacts, COST ACTION 734 "Impact of Climate Change and Variability on European Agriculture". COST, Florence, 320pp

Latour B (2005) Resembling the social. An introduction to actor-network theory. Oxford University Press, New York, 311pp

NOU (2003) Om odels og åsetesretten [About the allodial right.], Official Norwegian report by a committee constituted by the Ministry of Agriculture, NOU 2003/26, Gov Adm Serv, Oslo, Norway. 174pp

Schumacher EF (1999) Small is beautiful – a study of economics as if people mattered, Schumacher 25 Years Later. With Commentaries, Hartley & Marks Publishers, Vancouver BC, 286pp

Senge P, Smith B, Kruschwitz N, Laur J, Schley S (2008) The necessary revolution. How individuals and organizations are working together to create a sustainable world. Doubleday, New York, 406pp

Sivakumar MVK (2005) Impacts of natural disasters in agriculture, rangeland and forestry; an overview. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Heidelberg and Berlin, 367pp

Sivertsen TH (2005) Reflections on the theme of classifying, documenting and exchanging meteorological data, Letter to the editor. Atmos Sci Lett 6:171–175

Sivertsen TH (2006a) Applied agrometeorology, applied agrobiology and the hypothetico-deductive principle. Available at the INSAM website (www.agrometeorology.org) at the Agromet Market Place of 12 April

Sivertsen TH (2006b) Quality considerations on meteorological parameters to be used for modeling UV-radiation. In: Slusser JR, Schafer K, Comeron A (eds), Remote sensing of clouds and the atmosphere XI, Vol. 6362. The International Society for Optical Engeneering' (SPIE), Stockholm, pp 6360Z/1–9

Škvarenina J, Tomlain J, Hrvol' J, Škvareninová J, Nejedlík P (2009) Progress in dryness and wetness parameters in altitudinal vegetation stages in West Carpathians: time-series analysis 1951–2007. IDŐJÁRÁS, Proceedings from the Oscarsborg Symposium, June 2008, 113:47–54

Stigter K (2008) Panta rhei: changes in agrometeorological adaptation strategies to climate change. First Keynote Lecture at the Opening Session of the Combined Conference of the South African Society of Crop Production, the Soil Science Society of South Africa, the Southern African Society for Horticultural Sciences and the Southern African Weed Science Society, Grahamstown, 22 January [PowerPoint presentation available from organizers and the author]

United Nations (1987) Report of the world commission on environment and development. General Assembly Resolution 42/187, 11 December 1987, UN, New York, no pages

Womersley M (2002) A peculiarly American green: religion and environmental policy in the United States. Unpublished Dissertation, University of Maryland, School of Public Policy, no pages

Zhao Caixia, Zheng Dawei, Stigter CJ, He Wenqing, Tuo Debao, Zhao Peiyi (2006) An index guiding temporal planting policies for wind erosion reduction. Arid Land Res Manag 20: 233–244

IV.4 Expert Systems

Andrew Challinor

Expertise is the basis for scientific advances as well as for application of scientific results, of the knowledge involved and of the understanding necessary in actual production conditions. We are interested here in the latter with respect to developing countries. How can scientific advances in agriculture and meteorology best serve the needs of the developing world? Many of these advances are technologically driven, rather than needs driven. Whilst it is now common for research and development projects in meteorology to incorporate a component on applications and/or impacts (Challinor et al. 2009), does this go far enough towards addressing real world needs?

Stigter et al. (2005) and Washington et al. (2006) argue independently that, among others in Africa, developing coping mechanisms for climate variability was and is the logical first step in dealing with climate change. Response farming is the best known indigenous coping mechanism that in the course of time did get scientific recognition and support (Stigter 2008a; Winarto et al. 2008). Many traditional expert systems are still in place to this end (Stigter et al. 2005) but many are also loosing their efficiency due to climate and other changes (Box IV.4).

Box IV.4 (Contributed by Kees Stigter)

Traditional farmers in parts of northern Nigeria define the onset of rains as "the day of the first good rain after the Moslim fasting period Ramadan, provided it is at least 7 months since the date of the last effective rain of the previous season". This means that if the end of the Ramadan is before the 7-months count (due to the shifting of the lunar calendar which determines the Ramadan), the latter supersedes. Tying the end of the Ramadan to the beginning of the cropping season symbolizes the local belief that after fasting the first good rain is blessed by God. Discussions with the participating farm-

A. Challinor (✉)
University of Leeds, Leeds, UK
e-mail: a.j.challinor@leeds.ac.uk

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_104,

ers learned that not all famers have the same definition of "first good rain" and that such definitions are also depending on the moment in time this rain is observed and the history of scattered rains till that moment (Onyewotu et al. 1998).

For northern Nigeria four "scientific" methods of determining the onset of the rainy season were intercompared by Ati et al. (2002). Best results were obtained with the Kowal and Knabe (K&K) method. For defining the onset date of annual rains in Nigeria "scientifically", they used a combination of accumulated rainfall totals and rainfall/evapotranspiration relations as criteria. We used the sixth day of "the first decade in the season in which the amount of rainfall is equal or greater than 25 mm, but with a subsequent decade in which the amount of rainfall is at least equal to half the evapotranspiration demand". Compared to all "scientific" methods, the "Ramadan" method described above worked most poorly in the 30 years studied, giving very early onset dates and therefore many false starts, due to the occurrence of damaging dry spells.

The K&K method has the obvious disadvantage that one has to wait another decade after the first one with rain greater than 25 mm, but the other methods had even larger problems in practice. Because this method considers crop water requirements, it gives more realistic onset dates. However, for the environment under consideration in many years false starts were still recorded. Ati et al. (2002) proposed a hybrid method, combining the rainfall/evapotranspiration criteria of K&K with a dry spell criterion of 7 days. If resowing had to be prevented, such a test for false starts, so 7 days of consecutive drought shortly after planting, appeared necessary. This would further delay sowing time and shorten the growing season. However, using the above mentioned way, this can be started up with the rainfall data in the 14 days (4 days after the sixth day of the first decade (with more than 25 mm) and the full subsequent decade for the rainfall/evapotranspiration criterion) one is anyway waiting after the first preliminary onset date determined.

Millet yields were between 20 and 40% lower when the "Ramadan" method was used for planting date determination compared to using K&K's method (Onyewotu et al. 1998). This was true for fields managed by farmers as well as in fields managed by research teams (Onyewotu et al. 2003). This was in 2 years without false starts with K&K's method.

Ideally, an agrometeorological advisory body should be formed by the government or NGOs that would be responsible, in a participatory approach with farmers and trained intermediaries, for predicting the onset dates "on line". This could guide decision making on (preparation of) sowing and on the safest types/varieties of crops to be selected. For such work the suggested hybrid method using actual daily rainfall could be used. From accumulated experience for each station or farmer's plot where rainfall is measured – and such calculations can be made – it could then be investigated whether the waiting period for dry spells could be further reduced or not.

This would mean that one could make use of increasingly improved expertise over time. Increasing climate variability is this way studied also. Use of predicted safe planting dates is only an early stage in response farming, where knowledge of previous seasonal rainfall patterns is also incorporated into decision making (Diarra and Stigter 2008). Recent developments in improved climate prediction have to be closely followed for operational applications in this context (Ati et al. 2002).

Modern expert systems require data, which is a serious constraint on climate science in non-industrialized countries. Hence it may be more weather stations, rather than more climate simulations, that are needed in order for scientific understanding, and the coping capacity that it informs, to grow. A good example is the development of warnings for crop diseases (Gleason et al. 2008). Observations can also have more direct benefits, as part of a programme of participatory research. For example, in Columbia rain gauge data have been used to correct farmers' perception of the principal growing season (Oberthür, personal communication 2007).

The issue of data availability [as a support system, see Part I of this book] is one example of how science may be allied more closely with the needs of society. It suggests that science might be better tailored to needs by being less driven by technology, and even perhaps curiosity. Instead, one might start with the needs of society, and carry out science accordingly (e.g. Stigter 2008b).

The problem with this is that the needs of society are highly diverse, both geographically and between people within a given region and even within the same village (Chambers 1990; Stigter et al. 2007). Hence studies of decision support for cropping systems in different geographical and economical conditions are likely to differ in their conclusions (e.g. Gadgil et al. 2002; Hansen 2005). One way of ensuring relevance is to extract generalities from specific case studies, as is done in agent based modeling of the response of farmers to weather forecasts (Bharwani et al. 2005). However, these models often remain strongly site specific.

Starting from societal needs has implications for relevance, then a scientific study may not be relevant beyond the region in which it was conducted. Relevance is also affected by the methods used. In practice there is often a trade-off between relevance and accuracy. Quantitative methods may be able to simulate climate, and even link it to crop yield (see e.g. Challinor et al. 2003); however, the relevance of these simulations to a farmer may be low. In contrast, farming systems develop highly relevant, but perhaps not-so-accurate, expert information systems.

These are often in the form of proverbs, such as "Uttara chusi, yattara gampa" ("Wait for rainfall during September 13–26; if it fails, leave the place"), from south India. Whilst it is no doubt true that the Uttara rains are important for crops, the accuracy of this proverb will depend on the crop, the planting date, crop management, and development of the season pre-Uttara.

Wheeler et al. (2005) tested this proverb against their crop model as a form of predicting crop failure. They found their model to be better at simulating the three lowest-yielding years than the proverb. However, this analysis contrasts formal and local expert knowledge using the constructs of science (empirical measurement of yield and rainfall, simulation models) rather than those of society (livelihoods, income).

In other words, such a comparison does not prove that a model is more *useful* than a proverb; merely that it is more accurate for a given metric of crop productivity, using a given dataset. However, there are of course also examples in which a scientific method is assessed to be superior by farmers and scientists alike, after joint participatory on-farm experiments that took place in the livelihood of farmers (Box IV.4). But we have an actual improvement only if such scientific expertise can be routinely provided to farmers in jointly organized response farming (e.g. Ati et al. 2002; Diarra and Stigter 2008; Winarto et al. 2008).

Even where scientific information is both accurate and useful, the information often does not reach those who need it (e.g. Stigter 2008b), due to non-existing bridges between products and users (Stigter 2008c). Even where information is made available, particularly in developing countries but also elsewhere, it is very often not used, either because of a lack of resources or because of other logistical barriers (e.g. Gleason et al. 2008). Where seasonal forecasts are available, for example, both accuracy and usefulness, along with other constraints, can limit the uptake of forecast information (Patt and Gwata 2002; Stigter 2004). The format of forecasts, and their probabilistic nature, can also be barriers to their use.

One way around these problems is to have organisations designed specifically to use forecasts, rather than attempt to have them used directly by farmers. Agricultural extension workers and crop insurance schemes are two examples of this. The most recent form of this approach is the training of farmers in Farmer/Climate Field Classes by extension workers as intermediaries but also using other local expert systems and farmer innovations (Stigter 2008a, c; Winarto et al. 2008). These can be seen more broadly in terms of the mainstreaming of climate information, or “climate proofing”, which are ways of integrating knowledge into decision making structures.

Recent advances in weather and climate forecasting include the use of multi-model ensembles (e.g. Hagedorn et al. 2005) and the potential to produce forecasts seamlessly at a range of timescales (WCRP 2007). Multi-model ensemble techniques are an efficient way of providing information for climate impacts, since they use existing models and so make good use of globally available computer resources (see e.g. Palmer et al. 2004). Ensemble predictions systems can produce skilful simulations of weather and of crop yield, particularly in tropical regions where predictability is highest (Challinor et al. 2005). There is a consensus that there is potential to increase the skill of seasonal forecasts (WCRP 2007). The question, in the light of the above discussion on needs driven science, remains how useful these developments are likely to be. Locally established expert systems are often more useful but less comprehensive and farmer innovations appear much easier to disseminate (Stigter 2008d). Ways have to be found to use results of both in training of farmers for assistance in decision making.

A similar question can be asked of developments in crop modeling. Recent advances include the integration of ensemble prediction systems with the modeling of impacts such as those on agriculture (e.g Collins and Knight 2007; Lejenäs 2005; Challinor et al. 2005), so that at least some of the inherent uncertainties in prediction are quantified. This development has needed methods to bridge the gap in spatial scale on which crop and climate models operate (Hansen and Jones 2000). Process-based models have been specifically designed to operate on the spatial scale of climate models (Challinor et al. 2004). These models tend to be less complex than the more location-specific decision support models (see e.g. Boote and Jones 1998).

A model with many parameters is likely to have a relatively large number of unconstrained parameters, increasing the risk of reproducing observed yields under test conditions without correctly representing the processes involved. Thus the model may be in error when run for another location and/or year. Having fewer parameters can reduce the risk of over-tuning. This more pragmatic approach may result in the conclusion that many models can give a good fit to observations, so that there may be more than one acceptable model (Beven 2006). In crop modeling, this approach has the advantage of modeling the yield determining processes without an excess of parameters (see Sinclair and Seligman 2000).

What insight does a needs driven perspective give into the appropriate types of crop models and their use? The more complex models simulate processes that may explain the root cause of observed phenomena – for example declining yields due to poor nutrient cycling. In theory this can inform farmers how much fertiliser to apply; in practice, the majority of farmers will not be able nor willing to use such systems. Similarly to climate forecasts, there may be organisations better-suited to use such information. The benefit of these modeling systems may come through "discussion support" rather than decision support (Hansen 2005). However, client appropriateness and user friendliness of these products are conditions that should be fulfilled by specially trained intermediaries working with the providers of such types of information. Otherwise there remains still a big chance that farmer needs and priorities are not met but solutions found are still in search of problems to be solved.

A similar argument can be applied to yield forecasting systems: forecasts based on systems such as the skilful probabilistic crop yield forecasting system of Challinor et al. (2005) provide potentially useful information ahead of the harvest. This information, delivered to the right people at the right time, could be used to mobilise resources and alleviate food shortages in low-yielding years. It could also be used to provide advice on crop scheduling. However, even if these are priorities, the use of all of this scientific expert knowledge depends on the existence of appropriate structures and institutions for the dissemination of information, such as in organized response farming and other issues suitable for Farmer Field Schools, and appropriate resources to ensure that it is used beneficially.

References

Ati OF, Stigter CJ, Oladipo EO (2002) A comparison of methods to detect the onset of the growing season for some stations in the Sudan Savanna of Northern Nigeria. Int J Climatol 22:731–742

Beven K (2006) A manifesto for the equifinallity thesis. J Hydrol 320:18–36

Bharwani S, Bithell M, Downing TE, New M, Washington R, Ziervogel G (2005) Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa. Philos Trans R Soc Lond B 360:2183–2194

Boote KJ, Jones JW (1998) Simulation of crop growth: CROPGRO model. In: Peart RM, Curry RB (eds) Agricultural systems modeling and simulation. Marcel Dekker Inc, New York, pp 651–692

Challinor AJ, Slingo JM, Wheeler TR, Craufurd PQ, Grimes DIF (2003) Toward a combined seasonal weather and crop productivity forecasting system: determination of the working spatial scale. J Appl Meteorol 42:175–192

Challinor AJ, Wheeler TR, Slingo JM, Craufurd PQ, Grimes DIF (2004) Design and optimisation of a large-area process-based model for annual crops. Agric For Meteorol 124:99–120

Challinor AJ, Slingo JM, Wheeler TR, Doblas-Reyes FJ (2005) Probabilistic hindcasts of crop yield over western India. Tellus 57A:498–512

Challinor AJ, Osborne T, Morse A, Shaffrey L, Wheeler T, Weller H (2009) Methods, skills and resources for climate impacts research. Bull Am Meteorol Soc 90:825–835

Chambers R (1990) Microenvironments unobserved. Gatekeeper Series No. 22. International Institute for Environmental Development, London, 15pp

Collins M, Knight S (eds) (2007) Ensembles and probabilities: a new era in the prediction of climate change. Papers of Theme Issue. Philos Trans R Soc Lond A 365(1857):1955–2191

Diarra DZ, Stigter K (2008) Operational meteorological assistance to rural areas in Mali: development-results-perspectives. Translation from the French of Conclusions and Recommendations of a recent French summary report. Available at the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology" of 19 February 2008

Gadgil S, Rao PRS, Rao KN (2002) Use of climate information for farm-level decision making: rainfed groundnut in southern India. Agric Syst 74:431–457

Gleason ML, Duttweiler KB, Batzer JC, Taylor SE, Sentelhas PC, Monteiro JEBA, Gillespie TJ (2008) Obtaining weather data for input to crop disease-warning systems: leaf wetness duration as a case study. Sci Agric (Piracicaba, Braz) [online] 65(special issue):76–87. http://www.scielo.br/pdf/sa/v65nspe/a13v65nsp.pdf

Hagedorn R, Doblas-Reyes FJ, Palmer TN (2005) The rationale behind the success of multi-model ensembles in seasonal forecasting – I. Basic concept. Tellus 57A:219–233

Hansen JW (2005) Integrating seasonal climate prediction and agricultural models for insights into agricultural practice. Philos Trans R Soc Lond B 360:2037–2047

Hansen JW, Jones JW (2000) Scaling-up crop models for climatic variability applications. Agric Syst 65:43–72

Lejenäs H (ed) (2005) Special issue: development of a European multi-model ensemble system. For seasonal to interannual prediction (DEMETER). Tellus 57A:217–512

Onyewotu LOZ, Stigter CJ, Oladipo EO, Owonubi JJ (1998) Yields of millet (Pennisetum typhoides) as a function of multiple shelterbelt protection in semi-arid northern Nigeria, with a traditional and a scientific method of determining sowing date. In: Van Duivenbooden N, Neeteson JJ (eds) Using scientific and indigenous knowledge at different scale levels to develop sustainable agriculture in the Sudano-Sahelian zone of West Africa. Netherland J Agric Sci 46:53–64

Onyewotu LOZ, Stigter CJ, Abdullahi AM, Ariyo JA, Oladipo EO, Owonubi JJ (2003) Reclamation of desertified farmlands and consequences for its farmers in semiarid northern Nigeria: a case study of Yambawa rehabilitation scheme. Arid Land Res Manag 17:85–101

Palmer TN, Alessandri A, Andersen U, Cantelaube P, Davey M, Déqué M, Díaz E, Doblas-Reyes FJ, Feddersen H, Graham R, Gualdi S, Guérémy JF, Hagedorn R, Hoshen M, Keenlyside N, Latif M, Lazar A, Maisonnave E, Marletto V, Morse AP, Orfila B, Rogel P, Terres JM, Thomson MC (2004) Development of a European multi-model ensemble system for seasonal to interannual prediction (DEMETER). Bull Am Meteorol Soc 85:853–872

Patt A, Gwata C (2002) Effective seasonal climate forecast applications: examining constraints for subsistence farmers in Zimbabwe. Global Environ Change Hum Pol Dim 12:185–195

Sinclair TR, Seligman N (2000) Criteria for publishing papers on crop modelling. Field Crops Res 68:165–172

Stigter CJ (2004) The establishment of needs for climate forecasts and other agromet information for agriculture by local, national and regional decision-makers and users communities. In: Applications of climate forecasts for agriculture. Proceedings of the RA I (Africa) Expert Group Meeting, Banjul, December 2002. AGM-7/WCAC-1, WMO/TD 1223, Geneva, pp 73–86

Stigter K (2008a) Agrometeorological services under a changing climate: old wine in new bags. WMO Bull 57:114–117

Stigter CJ (2008b) Agrometeorology from science to extension: assessment of needs and provision of services. A review. Agric Ecosyst Environ 126:153–157

Stigter CJ (2008c) Policy support for capacity building (in weather and climate services focused on agriculture). In: Report of the WMO/CAgM management group meeting in Obninsk, Russian Federation, 12 June, Geneva, 87pp

Stigter K (2008d) Operational agrometeorology: problems and perspectives. Souvenir, International Symposium on Agrometeorology and Food Security, CRIDA, Hyderabad, pp 41–47

Stigter CJ, Zheng Dawei, Onyewotu LOZ, Mei Xurong (2005) Using traditional methods and indigenous technologies for coping with climate variability. Clim Change 70:255–271

Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi YM (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha R (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg, pp 171–190

Washington R, Harrison M, Conway D, Black E, Challinor A, Grimes D, Jones R, Morse A, Kay, G, Todd M (2006) African climate change: taking the shorter route. Bull Am Meteorol Soc 87:1355–1366

WCRP (2007) World Climate Research Programme Workshop on seasonal prediction. Position paper. http://www.clivar.org/organization/wgsip/spw/spw_position.php

Wheeler TR, Challinor AJ, Slingo JM, D. Grimes DIF, Craufurd PQ (2005) Forecasting the harvest: from proverbs to PCs. Biologist 52:45–49

Winarto Y, Stigter K, Anantasari E, Hidayah SN (2008) Climate field schools in Indonesia: improving "response farming" to climate change. Low Ext Input Sust Agric (LEISA) Mag 24(4):16–18

IV.5 Education, Training and Extension

Kees Stigter

Already for quite some time, I have been pleading for the establishment of an extension agrometeorology, in which also suitable intermediaries are trained and equipped to better articulate the needs of the farmers and farming communities for weather services. See also Box IV.5. The users as well as those intermediaries, making locally available some kinds of weather and climate related information more suitable than what is routinely generated (e.g. Winarto et al. 2008), should get much better educated/trained for absorption and establishment of agrometeorological services (Stigter 2003).

Box IV.5

While the scientific principles are the same in all countries, the potential applications and the conditions under which they have to be used vary greatly between countries in different climates and at different stages of development. Hence this also applies to education, training and extension to put them into effect. Training programs at all levels must therefore be adapted to national and regional needs. In recent operational developments this includes developing extension agrometeorology around the establishment of agrometeorological services, particularly in non-industrialized countries (Stigter et al. 2010; see also Part I). With an increasing rate of application in the developing world, for their agrometeorology, with their more abundant weather and climate disasters, and their endangered environments, the definition of agrometeorology was widened. This was also the first gradual widening of priorities (Stigter 2009a).

As indicated in Part I already, society and economics are no agricultural meteorology but consequences and use (that is management!) of water,

K. Stigter (✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_105,

radiation/heat and air in society and economics, as far as the agricultural production environment is concerned, slowly became an undercurrent in agricultural meteorology (WMO 2006). This is a second gradual widening (Stigter 2009a, see also Part I, Sect. I.2.5). The widening of the definition of agricultural meteorology as well as the second widening in subjects have largely been missed by training and education, and more so in developing countries (Stigter 2009a). The analysis made in Sect. I.3.3 has also serious consequences for training, education and extension, so for curricula. This applies most strongly for developing countries (Stigter 2009a).

For too long non-industrialized/southern countries have been tied to and have been imitating educational systems and their underlying values from industrialized northern countries which are alien to their rural cultures (Van den Bor and Shute 1991). Happy enough we are closer than ever before to the farmers, but unfortunately we are farther away than ever from the policy makers (Stigter 2006a, b; see also Box IV.6).

Box IV.6

Some years ago Jeffrey Sachs (2006) wrote (among many other places published in the Jakarta Post) that "on a recent visit to Africa, a senior agricultural scientist said that in today's world, the scientist is closer than ever before to the farmer, but farther away than ever from the policy maker". He was quoting my lecture in Khartoum for the Open University at the Institute for Studies of the Future, on 23 April 2005 (Stigter 2006a, b).

He continued to argue that politicians don't understand science, and rarely seek the advice of scientists and engineers in addressing major issues. It is easy to dismiss the suggestion that technology can save the day. Nevertheless, it's time to recognize that governments are ill-equipped to understand the sophisticated technological challenges and opportunities facing the world, and that new ways are needed to ensure that science and technology are given the prominence needed to address a wide range of increasingly urgent global problems.

Now is the time for every major international agency and national government to assume responsibility for gaining the scientific and technological expertise that they will need in the twenty-first century (Sachs 2006) [Already in Sect. I.5 of this book I have mentioned under which conditions this has to be done. KS.].

The time has come to reestablish public financing systems that enable small farmers in the poorest countries, notably those farming on 2 ha or less, to gain access to needed inputs of high-yield seeds, fertilizer, and small-scale irrigation. Malawi has done this for the past three seasons, and has doubled its food production as a result. Other low income countries should follow suit. Donor governments, including the oil-rich countries of the Middle East, should help finance the World Bank's new efforts. The world should set as a practical goal of doubling grain yields in low income Africa and similar regions (such as Haiti) during the next 5 years. That's achievable if the World Bank, donor governments, and poor countries direct their attention to the urgent needs of the world's poorest farmers (Sachs 2008a).

Sachs (2008b) also collected good news in bad times, using among others as examples that Malawi has doubled its annual food production since 2005 through a pioneering effort to help its poorest farmers (that is now being emulated throughout Africa) and that Mali is eager to scale up investments in agriculture, health, education and infrastructure in its 166 poorest communities. The plans are detailed, thoughtful, credible and based on proven successes that the government already achieved [as we have exemplified in this book already a few times. KS.]

In yet another of his Project Syndicate Commentaries, Sachs (2009) added "extension training" to the list of "improved seeds", "fertilizer" and "irrigation systems". As important in these matters is the Financial Coordination Mechanism that he now mentioned, making it possible for the aid money flow to be assured. This would mean that finally the promised billions could also be used in extension training and would really become available!! Financing institutionally Climate Field Schools related to agrometeorological and related services would for us be the most important consequence of these developments.

At an operational level, if also in educational work data analyses and data applications are at a more local, district or on-farm level during the growing season, data analysis skills need to be taken through to decision making "trees" to be of practical use to farm managers, for irrigation scheduling, crop/livestock disease and pest control and other daily/weekly farm operations (such as weeding and fertilization) (Stigter et al. 2010). For such agrometeorological services, NMHSs and research agrometeorologists need for example a good basis in fundamentals and applications of short term weather forecasting together with the crop/livestock requirements of temperature (i.e. critical values), daylength and water (Walker 2005).

High quality basic syllabi in agrometeorology do exist (e.g. Lomas et al. 2000; Stigter et al. 2010). As indicated also in the GAMP, the previous analysis shows the necessity of additions (Stigter 2009a). Some additions that can be mentioned for applied agrometeorology follow from our analyses so far (Stigter 2009a):

- National framework of agrometeorology

It will enliven teaching if a national framework of agrometeorology can be set, showing local applications, developments and needs. PhDs in Sudan, Nigeria and

Kenya in the TTMI/AN project (Stigter and Ng'ang'a 2001) have all used their local results and those of the supportive MSc-students in their teachings, together with the literature examples they collected for their theses. In one of my Roving Seminars (KNMI 2009) I prefer to carry out Master Classes in which local MSc- and PhD-students talk about their research. I do first ask questions and give comments, and then there is a general discussion with the rest of the audience. I always try to guide the discussion towards questions like "Why is this research done, why was it chosen?"; "What are the results to be expected from the research?"; "What can we do with these results locally?"; "What local farmer problems are addressed this way?".

It is noteworthy to mention that in most cases there has been very little thinking in these directions. For me, that is very much a waste of energy and efforts of scarce talent. From the beginning it should be the wish to have MSc-research and PhD-research contributing to solving well identified farmer priority problems. Or at least to contribute to understanding these problems scientifically from their points of view. This includes testing and understanding of traditional expert knowledge for a good comparison with scientific approaches (see for example Box IV.4 in Chap. IV.4 on Expert systems). This way a national agrometeorology framework is built up, agrometeorology is used locally and related to problem solving.

- International framework of agrometeorology

History of progress and more recent developments in international agrometeorology will show where the national framework of agrometeorology can still be widened. Complementary developments in CAgM and INSAM, as widely published on their websites, will be able to illustrate this. It is one of the tasks of such organizations to translate these developments towards education. This book as a whole is meant to stimulate this, although Part IV is particularly about the science that can be used in the support systems for institutionalized agrometeorological services and the fallacies and difficulties experienced in that use.

In CAgM for example the national progress reports are published to make such an international framework possible by using results to which attention has been brought that way. In INSAM, the possibility to contact people with the same or a similar field of interest also encourages that inernational framework and so do the contents of CAgM and INSAM websites.

- Training in multi-disciplinary problem solving

Two examples from a recent report on the agrometeorology at Free State University, Bloemfontein, South Africa (Stigter 2006c). "The Influence of Climate on Agricultural Practices" is a very original course given there in a very original style, using the "Problem Based Learning" method. Subjects used as examples are many and can easily vary. This is a first course where fresh research results obtained by the lecturers or under their supervision (or even relevant problem focused results obtained elsewhere in Africa) could be worked into the curriculum in the course of time. Cases of local farming problems brought up, tackled and (partially) solved, would be a best choice.

"Operational Agrometeorology" is again such an original course in an original setting in an attempt to familiarize students in the last year of their BSc study with communicating with those in farming, those providing basic information and data and those who can use the research results. In this process, information detection skills, professional analytical skills and information transfer/communication skills are developed while reality determines the success. This is another course where problems brought up by African farmers as well as recently solved African problems in day-to-day management of farm operations and in long-term farm planning could time and again be worked into the course as scenarios (Stigter 2006c).

- Projects and seminars on specific regional problems and interests in agrometeorology

At all levels of teaching in agrometeorology, projects and seminars on local problems and fields of specific interest to local development will strengthen the national framework of agrometeorology. A multidisciplinary approach, also showing relations between agrometeorological components and components of other fields of applied science in problem solving should be given a chance here.

- Case studies of agrometeorological services and study tours to examples of their applications

Particularly at the advanced levels of courses, attention to agrometeorological services developed for the livelihood of farmers, and field studies of the same, will show students where the needs are in agricultural production and what agrometeorology can contribute to relief constraints.

In WMO (2010) it has been indicated that educational commitments that have recently been tried out, in addition to the still often failing classical agricultural extension, were among others Response Farming Advisory Teams (such as in the Mali Pilot Projects), new Roving Seminars for extension personnel or extension intermediaries or farmer facilitators or farmers themselves (such as for agrometeorology those of ANGRAU in India, WMO in Ethiopia and Agromet Vision in Iran, India, southern Africa and Indonesia), Farmer Visiting Schemes, Farmer Demonstration Facilities, Farmer Field Days and Farmer Field Schools (FFSs), including Climate Field Schools (CFSs) (such as those organized in Indonesia). For the latter, see also Sect. I.6.

According to WMO (2010), it has to be realized that such undertakings are often focused on solving certain priority problems identified by farmers, like in the Integrated Pest Management Field Classes that stood at the start of the FFS developments, but some are training the trainers. A most important conclusion is the need for local networking and national networking that should precede and follow such educational commitments. In addition to the follow-up of the training facilities themselves, this is the second institutionalization without which upscaling of successes will be much more difficult to reach.

The FFS/CFS alumni must remain in contact as farmer groups, also because the farmer to farmer extension remains one of the most important means of dissemination. Trainers/facilitators/intermediaries need to see each other and their trainers and they should be able to collect feedback from farmers. Curricula as in the Annexes of Part I have to be further developed, improved and multiplied, and networking is the only way to get that done. Modern communication techniques are ideal for organizing such networking and keeping it going, but rural meetings to exchange experiences face to face are indispensable as well.

Institutionally, this demands new educational commitments, on a large scale, by the providers of the products as well as by governments/NGOs; to renew the agricultural extension in approach and contents, both with strong participation of farmer groups that will come to the CFSs/FFSs, for new and improved needs assessments. Illiteracy, vulnerability, poverty and a high need for farmer differentiation are initial and boundary conditions of this new approach in educational commitments. External funding promised to Africa and internal funding promised by governments of giants like China, India and Brazil, but also by small countries like Malawi and Mali (see Box IV.6), should, among many other priorities, be used also on such institutionalized commitments (Stigter 2009b; WMO 2010).

References

KNMI (for Netherlands Government, compiled by Kees Stigter, second update, 2009) Capacity building in the area of agrometeorological services through roving seminars. Document originally distributed and presented as CAgM-XIV/INF.4 at the XIVth Session of the WMO CAgM, New Delhi, October/November 2006, 19pp

Lomas J, Collins J, Gachara S, Mukhopadhyay S (2000) Education and training in agrometeorology. CAgM Report 78, WMO/TD 990. Geneva, 36pp

Sachs JD (2006) Embracing science. Project Syndicate Commentary. January. http://www.project-syndicate.org/commentary/sachs107/English

Sachs JD (2008a) A new deal for poor farmers. Project Syndicate Commentary. May. http://www.project-syndicate.org/commentary/sachs141/English

Sachs JD (2008b) Good news in bad times. Project Syndicate Commentary. December. http://www.project-syndicate.org/commentary/sachs148/English

Sachs JD (2009) Urgent: a breakthrough against hunger. Project Syndicate Commentary. January. http://www.project-syndicate.org/commentary/sachs149/English

Stigter CJ (2003) The future of education, training and extension in agricultural meteorology: a new approach. In: Zheng Dawei (ed) The future of education and training in agrometeorology in China. Proceedings of a Workshop, China Agricultural University, Beijing, pp 2–11

Stigter K (2006a) Scientific research in Africa in the 21st century, in need of a change of approach. Afr J Agric Res 1:4–8

Stigter K (2006b) A contemporary history of a new approach to applied agrometeorology. Available at the INSAM website (www.agrometeorology.org) under "History of Agrometeorology" of 6 February

Stigter CJ (2006c) Agrometeorology at the University of the Free State, Bloemfontein, South Africa: a rapid appraisal. Agromet Vision, Bruchem and Bondowoso, 7pp

Stigter CJ (2009a) Agricultural meteorology over the years and new priorities and consequences for curricula. Chapter 3 In: Guidelines for curricula in agricultural meteorology. Supplement No. 2 to "Guidelines for the education and training of personnel in meteorology and operational hydrology", Vol. 1, WMO 258, Geneva. www.wmo.int/pages/prog/etr/documents/258_vol1_Supp_2_1.pdf

Stigter K (2009b) Scientific support to the establishment and validation of agrometeorological services. SciTopics, Elsevier. Research summaries by experts. Agricultural and Biological Sciences (Miscellaneous). http://www.scitopics.com/categories.jsp?domain=1100

Stigter CJ, Ng'ang'a JK (2001) Traditional Techniques of Microclimate Improvement African Network (TTMI/AN) Project for Research Training. Successful research training partnership case study for GFAR-2000, Global Forum on Agricultural Research, Rome. Available on CD-ROM from FAO

Stigter K, Baier W, Barrie I, Brunini O, Dommermuth H, Gat Z, Gommes R, Keane T, Chan Ah Kee, Lomas J, Milford J, Ravelo A, Rijks D, Samui RP, Walker S, Wang Shili, Weiss A (2010) General. Chapter 1 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Van den Bor W, Shute JCM (1991) Higher education in the third world: status symbol or instrument for development. Higher Educ 22:1–15

Walker S (2005) Role of education and training in agricultural meteorology to reduce vulnerability to climate variability. Clim Change 70:311–318

Winarto YT, Stigter K, Anantasari E, Hidayah SN (2008) Climate field schools in Indonesia: improving "response farming" to climate change. Low Ext Input Sust Agric (LEISA) Mag 24(4):16–18

WMO (2006) Commission for Agricultural Meteorology (CAgM). The first fifty years. WMO-No. 999, WMO, Geneva, 44pp

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. WMO Brochure prepared by CJ Stigter, WMO, Geneva, in press

IV.6 Meteorological Data to Support Farming Needs

Raymond P. Motha

The availability of appropriate meteorological and agrometeorological databases is a major prerequisite for studying and managing the processes leading to agricultural and forest production. The building of databases for meteorological, phenological, soil, and agronomic information is inevitably a major priority. The key steps to database management are pertinent climate and agrometeorological data processing; data quality control; data archiving; timely access to data; and of utmost importance, information dissemination for use in both agricultural research and operational programs.

Agrometeorological observations need to be collected throughout all food-producing areas of the world. Because of wide territorial scope, the basic national databases that include meteorological, climatological, agronomic, and crop phenological data are typically kept and maintained by the NMHSs. The building of these databases usually is dependent on the availability of technical personnel, and the hardware and software resources at the local, regional, and national levels. However, there are significant gaps that exist between the developed and developing countries. In the developed countries, personal computer technology, database software, and the adoption of advanced interpretative systems like Geographic Information Systems (GIS) have brought large data volumes closer to the end users. Great strides in the automation age have made data products more rapidly available to the user community in the industrialized countries (Doraiswamy et al. 2000).

While the use of agrometeorological data depends on the specifically defined purposes, the accuracy and the management of the unique data can be tailored to the user needs in readily available formats. In the developing countries, this technology is lacking, primarily because of limited resources, subsistence-level economics, and lack of donor support. This was recognized already over 25 years ago (e.g. Stigter 1984) but progress has been slow for the already given reasons. When the technology is made available, limited resources and capacity building opportunities often restrict the application of technology. Recent technological innovations are

R.P. Motha (✉)
United States Department of Agriculture, Washington, DC, USA
e-mail: rmotha@oce.usda.gov

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_106,

becoming more cost-effective and user-friendly, which is allowing greater utilization among the developing countries. However, it is still beyond the means of poor nations without donor support (e.g. Stigter and Ng'ang'a 2001).

The electronic transfer of data files via internet using File Protocol Transfer (FTP) and the World Wide Web (WWW) has advanced data transfer and information transfer to a new level. The WWW allows users to access text and images that are linked together electronically. The attributes of WWW include the flexibility to handle a wide range of data presentation methods to reach vast audiences around the globe. The WWW interface handles the communication between a remote server, where the data files reside, and the users' remote display capability. This interface is controlled by a series of scripts and programs, which execute commands to read, process, and display data products. The data can be stored in a self-describing file format. The scripts and programs to generate menus for the WWW interface can read this information that describes the content of the data file (i.e. metadata, e.g. Murthy et al. 2010).

The challenge is to manage increasing sources of data so that users can efficiently extract needed information for their specific applications. For example INSAM, the International Society for Agricultural Meteorology, has recently made accessible NASA selected "Online Weather and Climate Information for Agrometeorologists" from the website www.agrometeorology.org. The global climate community, and specifically the agricultural climate community, needs to incorporate new information technologies into a systematic design for agrometeorological data management for the developing world. The goal is to ensure that the climate and agrometeorological databases needed by the agricultural sector are collected, quality controlled, archived, and disseminated in a timely manner for all user needs.

Agricultural weather and climate data systems are necessary to expedite the generation of analyses, forecasts and other products that affect agricultural cropping decisions, cropping management decisions, irrigation scheduling, fire weather management, disaster preparedness, ecosystem conservation and management, and commodity trading and markets. Basic data collection activities should ensure that information on weather and climate, and their impact on crops, livestock, water and soil resources, and forest management, can be processed, analyzed, and distributed in the most efficient and timely manner, not only for storage and management, but also for information retrieval and information dissemination (Hubbard et al. 2001).

Agrometeorology as an interdisciplinary branch receives data from a variety of source disciplines and provides the information to a relatively wide scope of users, ranging from individual farmers to extension personnel to local government decision makers (Motha and Stefanski 2006). Agrometeorological station networks are designed to observe both meteorological and biological phenomena together with supplementary data pertaining to disasters and crop damages. Meteorological data must be considered as typically about physical elements that can be measured with relatively high accuracy, while other types of observation are, in many cases, much more subjective and vary with the observer (Burba 2001).

In collecting, managing and analyzing the data for agrometeorological purposes, the source of data and the methods of observation define their management approach. The number of parameters observed differs with the method of data collection. The method of field observation/quantification can be categorized into two major classes, manually observed stations (e.g. Murthy et al. 2010) and automated data collection stations (e.g. Hubbard and Sivakumar 2001) (see also Box IV.12 in Chap. IV.9). The Automatic Weather Station (AWS) can collect data at a desired range of frequencies from minutes to 24-h averages, depending on the need and data storage capacity. The data logger can be programmed to provide daily summaries in addition to the regular acquisition.

A combination of manual and AWS stations can complement each other to expand a denser agrometeorological network in a crop area. A third source for agrometeorological data that is gaining recognition for its complementary nature to the traditional methods (Doraiswamy et al. 1996; Das 2004; Saha 2004) is satellite remote sensing technology (see the same Box IV.12 in Chap. IV.9). Some developing countries are beginning to set up their own basic remote sensing centers that should be able to handle the required level of processing. Regional centers are set up to service surrounding countries such as in the African continent. The Food and Agriculture Organization (FAO) has been very instrumental in promoting and establishing these centers in developing countries. Programs such as the Famine Early Warning System (FEWS) sponsored by the US Department of State rely on remotely sensed data as a surrogate for agrometeorological data when no ground data are available (Rowland 2001).

The management of agrometeorological data in the electronic information age has become easier, faster, and more efficient. Yet, management of the data is perhaps one of the most critical processes in any design concept. There are several key areas where attention needs to be directed as one considers any particular design requirements, including data collection, data processing, quality control, archiving, data analysis and product generation, and product delivery (Monnik 2001; Huard and Perarnaud 2001; Puterbaugh et al. 2001).

The design of a data processing system is dictated by the needs of the user. This includes the type of data, frequency of observation, source of data, and the data delivery format. If the data are being delivered via high-speed satellite downlink, the process is very different from when being manually entered. Yet, both these extremes have a common data management requirement. They have to be accepted into the system. In other words, an information system has to have multiple data entry points, requiring multiple user/machine interfaces, which process multiple types of information.

The personal computer environment (or the networked workstation) offers flexible machine/human interfaces while the WWW adds dynamic and creative solutions not restricted to local computer systems or databases. In any event, the information that enters a database and is maintained in a computer as well as the products retrieved by users, are their responsibility. It is critical that a long-term relationship be established with both the data suppliers and product users, to ensure that the information is of the highest quality to properly guide decisions made by the user in the appropriate decision making process.

The essence of quality control (QC) is the assessment and improvement of imperfect information, by making use of other imperfect information. The following highlights some of the reasons for data QC (Meek and Hatfield 2001; Hubbard 2001):

- The exact information needed should be properly generated.
- Inconsistent data must be identified or will otherwise lead to incorrect decision preparation inputs.
- For operational needs problems have to be detected that require immediate maintenance attention.
- For some purposes, continuous data are required, even if such data are estimated.
- To maintain an audit trail on data for future needs to update documentation.
- Data are often important for legal or design considerations.
- An established QC process attaches individual data values with flags that allow software to select data tolerance levels for product generation.

Quality control should be thought of as an end-to-end process, which is integral to the successful acquisition, temporary storage, permanent archival, and subsequent retrieval, use and interpretation of the data and information produced by a network. In managing metadata, it is critical to maintain all known names and aliases and identification numbers for stations. The accurate identification of data collection stations, an obviously fundamental component of metadata, is more complex than it first appears. Geographic "place" names are the easiest and most user-friendly means of station identification. The following metadata base documentation is essential (Lazar et al. 1999):

- Station identity (site name, aliases, and all identification numbers including network identification)
- Location (coordinates, elevation, geopolitical placement, topography, etc.)
- Equipment/instrumentation and its exposure
- Data observing and data dissemination practices (network membership)
- Data inventory
- Temporal changes to any of this information.

The station history data will detail the changes in the station over time. This includes, but is not limited to, the location, naming, and equipment. Such documentation includes the following (Lazar et al. 1999):

- Station location changes (latitude, longitude, and elevation), station name changes
- Time of observation for each element and dates of any changes
- Beginning and ending dates for each reported element
- Addition or removal of element or sensor
- For hourly precipitation stations, type of rain gauge

- Type of recording equipment and dates of changes
- Observers' names and dates of service.

Conclusive statements on the importance of agrometeorological data in a climatic context in the operational needs of agricultural producers, researchers, and agricultural weather and crop forecasters are in Box IV.7. It is among others indicated there that data base management is meaningless if information is not readily available in a friendly format to the user community in time for appropriate decision making.

Box IV.7

The importance of agrometeorological data in a climatic context in the operational needs of agricultural producers, researchers, and agricultural weather and crop forecasters are gaining attention in the domestic and the international research communities. Databases have been developed in many countries although there are still quite some countries where there is a need for establishing databases that are accessible for their citizens and the international community. Modernization of data acquisition, data processing and data archiving can be a costly proposition but steps need to be taken to ensure that such data are archived in a standardized manner that can be useful. Computer technologies are advancing rapidly, and therefore it is unrealistic to try and articulate all potential solutions to agrometeorological information systems, for there are surely more technology solutions currently under development. It is hoped, however, that the reader has been exposed to some of the key elements of what should be considered in designing and implementing a computerized climate information delivery system.

But database management is meaningless if information is not readily available in a friendly format to the user community in time for appropriate decision making. As mentioned earlier, great progress has been made in the developed world, but a significant technology gap must be bridged to the developing nations that lack resources and must devote energies toward sustaining subsistence level security. The major focus needs to be directed toward the poorer farmers who are attempting to build a sustainable livelihood with the goal of boosting their socio-economic well-being. There must be more critical consideration for local needs and for emphasizing the local bottom up determination of how agrometeorology may help farmers solve their local needs (Stigter et al. 2007). From the latter's results it follows that for example in central and western regions of China, traditional modes of information flow and communication still occupy the main position. This is confirmed for many other developing countries (Stigter et al. 2007). Some data collection, data management and data use, may, for the time being, have to be adapted to such conditions in the generation and establishment of agrometeorological services (WMO 2010).

References

Burba G (2001) Illustration of flux footprint estimates affected by measurement height, surface roughness, and thermal stability. In: Hubbard K, Sivakumar MVK (eds) Automated weather stations for applications in agriculture and water resources management: current and future perspectives. Proceedings of an International Workshop, Lincoln,, March 2000. High Plains Climate Center, Lincoln,; WMO, Geneva, pp 77–86

Das HP (2004) Satellite-based agro-advisory service. In: Sivakumar MVK, Roy PS, Harmsen K, Saha SK (eds) Satellite remote sensing and GIS applications in agricultural meteorology. Proceedings of a Training Workshop, Dehra Dun, July 2003. WMO, Dehra Dun, pp 347–360

Doraiswamy PC, Zara P, Stem A (1996) Satellite remotely sensed data application in estimating crop condition and yields. Remote Sensing Applications, Norasa Publishing House, New Delhi, pp 220–240

Doraiswamy PC, Pasteris PA, Jones KC, Motha RP, Nejedlek P (2000) Techniques for methods of collection, database management, and distribution of agrometeorological data. Agric For Meteorol 103:83–97

Huard F, Perarnaud V (2001) Agrometeorological data management strategies and tools in France. In: Motha RP, Sivakumar MVK (eds) Software for agroclimatic data management. Proceedings of an Expert Group Meeting, US Department of Agriculture, Washington, October 2000, pp 43–54

Hubbard KG (2001) Multiple station quality control procedures. In: Hubbard K, Sivakumar MVK (eds) Automated weather stations for applications in agriculture and water resources management: current and future perspectives. Proceedings of an International Workshop, Lincoln, March 2000. High Plains Climate Center, Lincoln; WMO, Geneva, pp 133–138

Hubbard K, Sivakumar MVK (eds) (2001) Automated weather stations for applications in agriculture and water resources management: current and future perspectives. Proceedings of an International Workshop, Lincoln, March 2000. High Plains Climate Center, Lincoln; WMO, Geneva, AGM-3, WMO/TD No. 1074, 370pp

Hubbard KG, Hollinger HE, Xinhui Lin (2001) Standard meteorological measurements. In: Hubbard K, Sivakumar MVK (eds) Automated weather stations for applications in agriculture and water resources management: current and future perspectives. Proceedings of an International Workshop, Lincoln, March 2000. High Plains Climate Center, Lincoln; WMO, Geneva, pp 111–122

Lazar AV, Barthel CD, Kuiper DG (1999) Metadata strategies for the efficient management and exchange of data throughout a unified climate access network. Proceedings of the 11th Conference on Applied Climatology, American Meteorological Society, Dallas, January, pp 62–69

Meek DW, Hatfield JL (2001) Single station quality control procedures. In: Hubbard K, Sivakumar MVK (eds) Automated weather stations for applications in agriculture and water resources management: current and future perspectives. Proceedings of an International Workshop, Lincoln, March 2000. High Plains Climate Center, Lincoln; WMO, Geneva, pp 123–132

Monnik K (2001) Agrometeorological database management strategies and tools in South Africa. In: Motha RP, Sivakumar MVK (eds) Software for agroclimatic data management. Proceedings of an Expert Group Meeting, US Department of Agriculture, Washington, October 2000, pp 55–70

Motha RP, Stefanski R (2006) United States Department of agriculture's weather and climate information system for operational applications in agriculture. Meteorol Appl 13, suppl 1:31–47

Murthy VRK, with Milford J, Stigter K, Orlandini S, Oliphant A, Grant R, Wieringa J (2010) Agricultural meteorological elements and their observations. Chapter 2 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Puterbaugh T, Morris B, Shannon H, Rippey B, Brusberg M, Stefanki R (2001) Weather data management and software applications at the USDA joint agricultural weather facility. In: Motha

RP, Sivakumar MVK (eds) Software for agroclimatic data management. Proceedings of an Expert Group Meeting, US Department of Agriculture, Washington, October 2000, pp 17–32

Rowland J (2001) Spatial databases for agroclimatic applications In: Motha RP, Sivakumar MVK (eds) Software for agroclimatic data management. Proceedings of an Expert Group Meeting, WMO, Washington, October 2000, pp 159–170

Saha SK (2004) Retrieval of agrometeorological parameters using satellite remote sensing data. In: Sivakumar MVK, Roy PS, Harmsen K, Saha SK (eds) Satellite remote sensing and GIS applications in agricultural meteorology. Proceedings of a Training Workshop, WMO, Dehra Dun, July 2003, pp 175–194

Stigter CJ (1984) Forecasting and weather services for agriculture in Africa. In: Hawskworth DL (ed) Advancement of agricultural production in Africa. Proceedings of the Commonwealth Agricultural Bureau First Scientific Conference, Arusha. CAB, Farnham Royal, pp 327–331

Stigter CJ, Ng'ang'a JK (2001) Traditional techniques of microclimate improvement African network (TTMI/AN) Project for Research Training. Successful Research Training Partnership Case Study for GFAR-2000, Global Forum on Agricultural Research, Rome. Available on CD-ROM from FAO

Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi YM (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha R (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg/New York, pp 171–190

WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. WMO Brochure prepared by Stigter CJ, WMO, Geneva, in press

IV.7 Agricultural Physics

Gerard P.A. Bot

In Sect. III.6.B.(iv) we have dealt with some practical aspects of greenhouse choices but also already handled a few physical aspects of such agricultural production systems. The end of the 1950s and early 1960s saw the first books appear on physics in agriculture and plant environment (see Box IV.8). Where in this book basic science has only a role to remind us of the fundamentals dealt with in other books, but is shown only in a purely supportive function, we just illustrate the use of physics in agriculture with the example of phenomena happening in a greenhouse. It very well shows the practical advantages of even a very simplified quantitative physical approach.

Box IV.8 (Contributed by Kees Stigter)

A physicist by education (see Chap. IV.9) I want to get you back to the starting of my career in agricultural meteorology at a Physics and Meteorology Department of an Agricultural University in the Netherlands, in 1966. I was immediately confronted with three important books: (i) the second edition of Van Wijk (1966), who had accepted me as a member of staff, (ii) the somewhat less mathematically expressed and therefore for non-physicists (also educationally) somewhat better accessible book of Rose (1966) and (iii) the English translation of Ioffe and Revut (1966). In the latter, that appeared in Russian in 1959, the first sentence is: "This book deals with one of the newest branches of physics: agrophysics". Rose (1966) said that his title was not intended to imply a special kind of physics, but a consideration of agricultural problems, and some aspects of the environment and water relations of plants, from a physical point of view. Van Wijk (1966) explained in the first chapter on the "Physical method" that its essential characteristic is that it

G.P.A. Bot (✉)
Retired from Wageningen University and Wageningen UR Greenhouse Horticulture, Wageningen, The Netherlands
e-mail: gerardenvera.bot@hetnet.nl

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_107,

leads to a quantitative theory of the studied phenomena, expressible in mathematical language. In doing so, generalizations can be made from a limited amount of experimental data, i.e. the theory can be applied to circumstances differing from those encountered in the original experiments. This can rarely be done when a problem is approached in a purely empirical way. Van Wijk (1966) also argued in the same section that "the application of mathematical statistics to the design and interpretation of experiments does not change their empirical character". I have met much resistance to recognize this principal superiority of the physical method throughout the developing world but also among reviewers in almost the whole world of agriculture, leading to many misunderstandings on the approaches exemplified in Chap. IV.9. This physical approach is also illustrated and explained in this Chap. IV.7.

As soon as we talk about quantification of the agricultural production environment, it are physical factors of the plant environment or the biosphere that are studied, using the physics of instruments (e.g. Tschudnowski 1965; Hallaire et al. 1970; Fritschen and Gay 1979) and the laws of physics and biology (Tschudnowski 1965; Stigter 1982a, b; Monteith and Unsworth 1990). We get overlapping for different titles of books that are basically about differently focused work: plant water relations (e.g. Sestak et al. 1971), micrometeorology (Schwerdtfeger 1976), environmental biology (Woodward and Sheehy 1983) in the same environment. We even got specializations: irrigated and non-irrigated soils (Taylor and Ashcroft 1972), desertification (El-Baz and Hassan 1986), rural development (Swift 1983). But they all contain quantitative work on phenomena and processes in outdoor physics, sometimes taken into the laboratory and growth rooms to quantify and better understand specific processes (e.g. Slavik 1974). However, as one of my thesis supervisors, Kees de Wit, himself a student of Van Wijk, once said, plants in growth rooms never look like the same plants in the field, because the phenomena are different. In the above we mentioned pioneering books of the 1960s, 1970s and 1980s that contained elements of agricultural physics, and we tried to give the latter its well deserved place.

Light interception has direct effects on crop evaporation and release of sensible heat. With light transmittance of the cover τ_c for global irradiation (intensity I''_{glob}, Wm^{-2}) and Bowen ratio Bo (the ratio of released sensible and latent heat (e.g. Rose 1966; Van Wijk 1966; Monteith and Unsworth 1990)), greenhouse air temperature T_g can be estimated compared to outdoor air temperature T_a in its dependency on global irradiation from a simple energy balance approach.

The transmitted global irradiation $\tau_c\ I''_{glob}$ is absorbed by the crop, the part $Bo/(1+Bo)$ is released as sensible heat to the greenhouse air and the part $1/(1+Bo)$ as latent heat. In the steady state the sensible heat has to be released again from the greenhouse air to the ambient, giving rise to a temperature difference $T_g - T_a$.

The sensible heat passing the cover is proportional to the acting temperature difference $T_g - T_a$ between greenhouse and ambient air with proportionality factor Uc ($Wm^{-2}K^{-1}$), called heat transfer coefficient, due to convective and thermal radiation heat exchange. Hermetically enclosing the greenhouse interior, so without any air exchange through openings in the cover (ventilation), the absorbed sensible heat is passing the cover:

$$\tau_c I''_{glob}\left(\frac{\text{Bo}}{1+\text{Bo}}\right) = U_c(T_g - T_a) \tag{1a}$$

or

$$T_g - T_a = \tau_c I''_{glob}\left(\frac{\text{Bo}}{1+\text{Bo}}\right)/U_c \tag{1b}$$

The temperature difference between greenhouse air and ambient air is proportional to the global irradiation in this simple approach. With a typical transmission coefficient of 0.75, a typical Bowen ration of 0.5 and a typical heat transfer coefficient from the greenhouse air to the ambient air of 8 $Wm^{-2}K^{-1}$, the proportionality factor with the global radiation will be 1/32. This means that at global irradiation, greenhouse air temperature is already 10 K higher than ambient temperature. By allowing air exchange through openings in the cover, this temperature difference can be decreased. Then the simple energy balance, Eq. (1a), can be extended with the sensible energy carried by the ventilation air flow with volume flux Φ_V (m^3s^{-1}):

$$\tau_c I''_{glob}\left(\frac{\text{Bo}}{1+\text{Bo}}\right) = U_c(T_g - T_a) + \Phi_V \rho C_p(T_g - T_a) \tag{2a}$$

with ρC_p the volumetric heat capacity ($Jm^{-3}K^{-1}$) of the exchanged air.

Then the temperature difference can be expressed as:

$$T_g - T_a = \tau_c I''_{glob}\left(\frac{\text{BO}}{1+\text{BO}}\right)/(U_c + \Phi_V \rho C_p) \tag{2b}$$

Again the temperature difference between greenhouse air and ambient air is proportional to the global irradiation but now the proportionality factor decreases with increasing ventilation.

In Fig. IV.2 the temperature difference against global irradiation is given for various ventilation levels expressed in the refreshment rate n (number of refreshments per hour, so h^{-1}). This quantity is used in practice because it can be interpreted more easily than ventilation volume flux. Of course n and Φ_V are linked via

$$n = 3,600\Phi_V/V \tag{3}$$

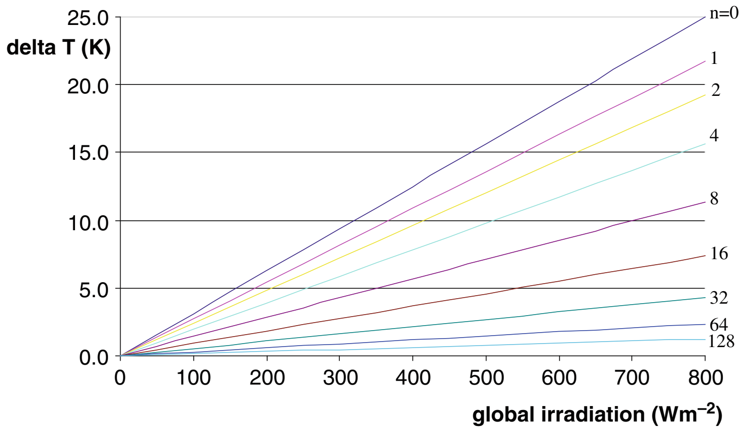


Fig. IV.2 Temperature difference between greenhouse air and ambient air as function of the global irradiation for various refreshment rates n (h^{-1})

While the simple heat balance is set up per m^2 of greenhouse, the volume V per m^2 equals the average height. In Fig. IV.2 the average height chosen is 3.6 m.This simple approach already gives a good order of magnitude of the greenhouse effect. For outdoor temperatures lower than greenhouse temperature, global irradiation helps to heat the greenhouse. If this effect is not strong enough (e.g. at low or no irradiation), then artificial heating is needed to maintain desired greenhouse air temperature as is indicated in Fig. III.6.2 of Sect. III.6.B.(iv). At low ventilation the effect can be increased by lowering the heat transfer coefficient Uc (Eq. 2b) from the greenhouse air to the outside, so by insulating the greenhouse. Thermal screens are an effective tool to do so, they can be opened in daytime, allowing solar radiation to enter, primarily for driving crop production but at the same time heating the greenhouse. Closed at night they reduce energy consumption. In northern regions low outdoor temperatures in winter are linked to low irradiation as earlier indicated in Fig. III.6.2 of Sect. III.6.B.(iv).

At outdoor temperatures higher than greenhouse air temperature the global irradiation very easily drives greenhouse air temperature to high levels not desired for optimal crop production. Then Fig. IV.2 indicates that high refreshment rates are needed to keep greenhouse air temperature within a few K from outdoor air temperature. According to Eq. (2b), also a lower Bowen ratio would help. Then more heat is released as latent heat so the evaporative cooling effect of the crop is more pronounced. However, this will only happen at low vapour content of the greenhouse air. Evaporative cooling equipment like pad and fan cooling or fogging systems can be applied at high outdoor air temperature in combination with low outdoor relative humidity (RH).

The greenhouse effect is not only on increasing the air temperature but also on increasing the vapour content. Especially in the heating season, when ventilation is not needed for cooling, greenhouse humidity can rise to levels with a risk of condensation and therefore fungal diseases or physiological disorders (Bakker 2001; Dieleman 2008). To estimate this risk, the simple approach can be extended to water vapour.

The latent heat as part of the absorbed solar radiation by the crop not released as sensible heat, is linked to the transpiration vapour flux by the latent heat ΔH ($J\ kg^{-1}$). In the steady state, this vapour flux has to be released from the greenhouse air by condensation on the relatively cold cover and by ventilation, as indicated in Fig. IV.3.

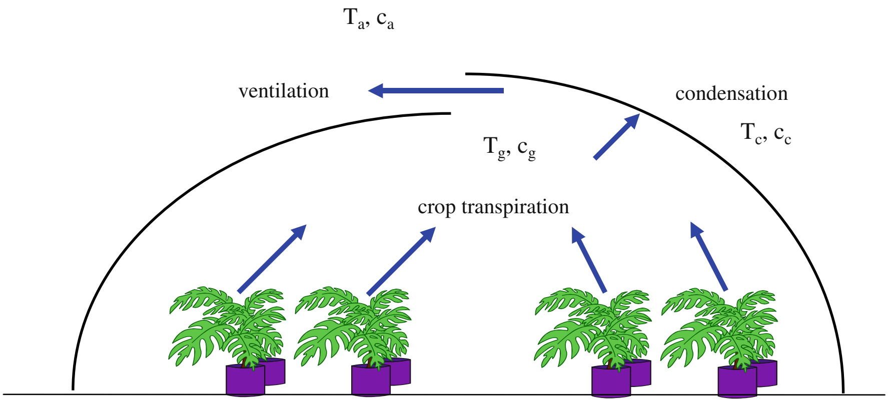


Fig. IV.3 Water vapour fluxes (soil evaporation neglected)

The driving force for condensation on the cover is the difference in vapour content of the greenhouse air c_g ($kg\ m^{-3}$) and the air at the inner surface of the cover c_c which is the saturated vapour content at cover temperature T_c. By ventilation greenhouse air is exchanged with outdoor air with vapour content c_a given by the outdoor conditions. So neglecting soil evaporation the steady state vapour balance over the greenhouse air can be set up:

$$\tau_c I''_{glob}\left(\frac{1}{1+\mathrm{Bo}}\right)/\Delta H = k_c A_c^*(c_g - c_c) + \Phi_V(c_g - c_a) \qquad (4)$$

with k_c the mass transfer coefficient from greenhouse air to the cover (ms^{-1}) and A_c^* the relative cover area (ratio of cover area and greenhouse area).

This equation cannot be evaluated as simply as the simple heat balance Eq. (2a) while both the outdoor vapour content and the vapour content at the cover play a role. However, two striking situations can be distinguished:

- *during the heating season no ventilation is needed to release excess sensible heat*

  The question is whether in this season crop transpiration, being dependent on irradiation, can be balanced by condensation against the cover. This is both dependent on the mass transfer coefficient-relative cover surface combination $k_c A_c^*$ and the difference in vapour content between greenhouse air and air against the cover $c_g - c_c$ as driving force. As the vapour content c_c is the saturated vapour content at cover temperature T_c, it depends on the cover temperature. While the cover temperature on its turn depends on the indoor and outdoor conditions, the latter also dependent on solar irradiation, the analysis is quite complex. In general, at cold outdoor conditions, the cover temperature will be low and condensation will balance crop transpiration easier, but at moderate outdoor conditions, condensation will not easily balance crop transpiration. So in the heating season growers apply ventilation to avoid too high RH. However, allowing cold dry outdoor air to be exchanged with warm humid greenhouse air implicates extra heating power to maintain greenhouse temperature at the desired level, so extra energy consumption. The limits for RH are very much dependent on the cultivated crop and the risk the grower is daring to take. In general about 25% of the energy consumption is due to the ventilation for dehumidification in the heating season, but this figure largely varies for different growers and crops. Additionally one has to realise that climate in a practical greenhouse is not homogeneous but shows large varying local temperature differences and therefore local RH differences. In well designed and computer controlled greenhouses local temperature differences up to 5 K are no exception.

- *during the summer season ventilation is needed to release excess sensible heat*

The question then is whether the ventilation capacity needed for the release of excess sensible heat is able to remove the water vapour from crop transpiration. The ventilation flux $\Phi_{V,h}$ to remove excess summer heat can be deducted from Eq. (2a) with neglected heat loss through the cover:

$$\Phi_{V,h} = \tau_c I''_{glob} \left(\frac{Bo}{1 + Bo} \right) / \rho C_p (T_g - T_a)$$

The ventilation flux $\Phi_{V,w}$ to remove water vapour can be deducted from Eq. (3) with neglected condensation against the cover:

$$\Phi_{V,w} = \tau_c I''_{glob} \left(\frac{1}{1 + Bo} \right) / \Delta H (c_g - c_a)$$

If $\Phi_{V,h} >= \Phi_{V,w}$ then the vapour removing capacity of the excess heat ventilation is sufficient to remove the transpired vapour and prevent too high RH. So if the ratio

$$\frac{\Phi_{V,h}}{\Phi_{V,w}} = Bo(\Delta H \rho C_p) \frac{(c_g - c_a)}{(T_g - T_a)} >= 1?$$

the vapour removal is no problem. The ratio of heat of evaporation ΔH per g and volumetric heat capacity ρC_p equals about 2, so for Bo = 0.5 a vapour increase of 1 g^{-3} must be linked to a temperature increase of 1 K. Figure IV.4 shows the vapour content as function of temperature for different RH. As outdoor

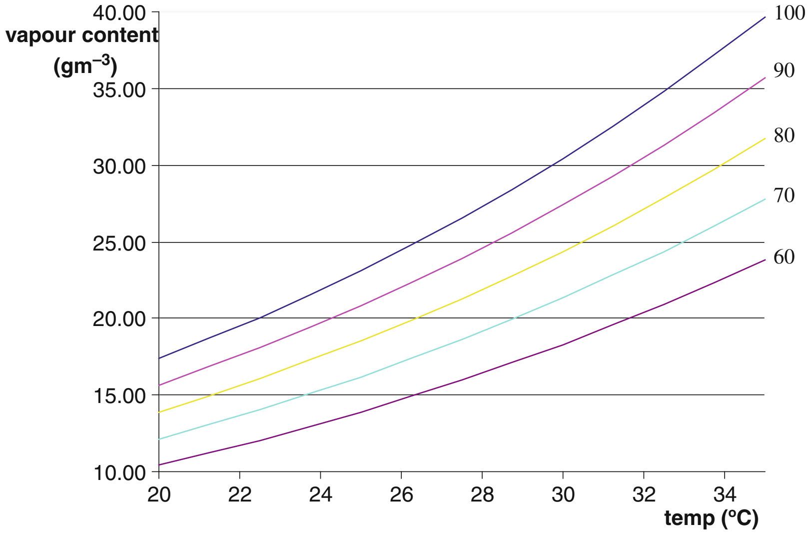


Fig. IV.4 Air vapour content as function of temperature at different relative humidity RH (%)

air RH generally is below 100% and in the greenhouse its temperature rises (see Fig. IV.2) it can be seen that the vapour-temperature increase condition can easily be met in the temperature range for the removal of summer excess heat.

So in the excess heat season, humidity control is not a major issue, the main concern is then to keep greenhouse temperature at acceptable levels. At high outdoor temperature, high ventilation rate is crucial to keep greenhouse air temperature close to outdoor temperature as indicated by Fig. IV.2. Ventilation is driven by pressure differences generated by the greenhouse-ambient temperature difference (buoyancy effect) and the wind field (Bot 1983; Boulard and Baille 1995). Crucial for the buoyancy effect is an inflow opening in the greenhouse side wall and an outflow opening in the top of the greenhouse, but there must be a driving temperature difference so this mechanism is not suited to keep greenhouse temperature near outdoor temperature. For the wind effect an inflow opening at the wind side and outflow openings at the leeside increase air exchange. Window opening size and shape can be optimised to realise high air refreshment rates even with insect nets in the ventilation openings to keep harmful insects out (Campen 2005). In this way even at tropical conditions it was possible to maintain acceptable greenhouse conditions (Impron et al. 2007).

From physically expressing the basic greenhouse mechanisms, it is demonstrated that the main outlines of greenhouse climate can be understood. In real greenhouses outdoor conditions can be very dynamic. Then the basic greenhouse mechanisms can be extended to the separate physical processes acting in the interaction between the outside conditions and the greenhouse climate for a greenhouse with defined physical properties (Bot 1983; De Zwart 1996). In this way computer simulation enables the calculation of dynamic greenhouse climate, which can be applied for year round analysis of greenhouse systems behaviour.

Linked with crop modeling it can also predict greenhouse crop production. Besides the interest in the dynamics of greenhouse climate also the spatial distribution can be of importance. Inhomogeneous temperature distribution causes inhomogeneous production. Moreover at cold spots condensation on parts of the crop may increase risk for the development of fungi. Also ventilation might be inhomogeneous due to local differences in the driving pressure distribution. To study greenhouse climate distribution, computational fluid dynamics (CFD) proved to be a powerful tool now applied worldwide (Mistriotis et al. 1997; Campen and Bot 2002; Roy and Boulard 2005).

References

Bakker JC (2001) Analysis of humidity effects on growth and production of glasshouse fruit vegetables. PhD Thesis Wageningen University, Wageningen, The Netherlands, 222pp

Bot GPA (1983) Greenhouse climate: processes from physical to a dynamic model. PhD Thesis Wageningen University, 240pp

Boulard T, Baille A (1995) Modelling of air exchange rate in a greenhouse equipped with continuous roof vents. J Agric Eng Res 61:37–48

Campen J (2005) Greenhouse design applying CFD for Indonesian conditions. Acta Hort 691: 419–424

Campen JC, Bot GPA (2002) Determination of greenhouse-specific aspects of ventilation using three-dimensional computational fluid dynamics. Biosyst Eng 84:69–77

De Zwart HF (1996) Analyzing energy-saving options in greenhouse cultivation using a simulation model. PhD Thesis Wageningen University, Wageningen, 236pp

Dieleman JA (2008) Effects of humidity on growth and development of tomato. Wageningen UR Horticulture Nota 519, Wageningen, The Netherlands [in Dutch], 57pp

El-Baz F, Hassan MHA (1986) Physics of desertification. Martinus Nijhoff, Dordrecht, etc, 471pp

Fritschen LJ, Gay LW (1979) Environmental instrumentation. Springer, New York, etc, 216pp

Hallaire M, Perrin de Brichambaut P, Goillot C (eds) (1970) Techniques d'étude des facteurs physiques de la biosphère. [Techniques for studying physical factors of the biosphere.] INRA, Paris, 543pp

Impron I, Hemming S, Bot GPA (2007) Simple greenhouse climate model as a design tool for greenhouses in tropical lowland. Biosyst Eng 98:79–89

Ioffe AF, Revut IB (eds) (1966) Fundamentals of agrophysics. Israel program for scientific translations, Jerusalem, 726pp

Mistriotis A, Arcidiacono C, Picuno P, Bot GPA, Scarascia-Mugnozza G (1997) Computational analysis of ventilation in greenhouses at zero- and low-wind speeds. Agric For Meteorol 88:121–135

Monteith JL, Unsworth MH (1990) Principles of environmental physics, 2nd edn. Arnold, London, etc, 291pp

Rose CW (1966) Agricultural physics. Pergamon Press, Oxford, etc, 226pp

Roy JC, Boulard T (2005) CFD predictions of the natural ventilation in a tunnel-type greenhouse: influence of wind direction and sensibility to turbulence models. Acta Hort 691:457–464

Schwerdtfeger P (1976) Physical principles of micro-meteorological measurements. Elsevier, Amsterdam, etc, 113pp

Sestak Z, Catsky J, Jarvis PG (1971) Plant photosynthetic production. Manual of methods. Junk, The Hague, 818pp

Slavik B (1974) Methods of studying plant water relations. Academia, Prague; Springer, Berlin, etc, 449pp

Stigter CJ (1982a) Environmental physics, agricultural research and development. Printed version of a public inaugural lecture in April 1980 upon nomination to Full Professor of Physics in July 1978. Inaugural Lecture Series, No. 30. Dar es Salaam University Press, Tanzanian, 54pp

Stigter CJ (1982b) The use of physics in agricultural research. Int J Environ Stud 19:269–271

Swift DG (1983) Physics for rural development. Wiley, Chichester, etc, 257pp

Taylor SA, Ashcroft GL (1972) Physical edaphology. The physics of irrigated and nonirrigated soils. Freeman, San Francisco, 533pp

Tschudnowski AF (1965) Was ist agrophysik? [What is agrophysics? German translation of a 1963 Russian original.] BG Teubner Verlag, Leipzig, 79pp

VanWijk WR (ed) (1966) Physics of plant environment, 2nd edn. North Holland Publishing Co, Amsterdam, 382pp

Woodward FI, Sheehy JE (1983) Principles and measurements in environmental biology. Butterworths, London, etc, 263pp

IV.8 Agricultural Chemistry in Agrometeorology: Relations with Groundwater Contamination

Tibor Stigter

Agrochemistry and soil chemistry have from the beginning been considered a part of agronomy (Ioffe and Revut 1966); soil water matters particularly a part of (agricultural) physics (Rose 1966; Van Wijk 1966). Together they stand at the basis of groundwater studies, where they particularly deal with the quantity and quality of groundwater recharge. The pressure of agricultural practices on groundwater resources is well-documented.

This chapter aims to provide some examples of problems that arise, including a very brief overview of the chemistry behind the contamination phenomena, after which mitigation strategies are discussed. Such strategies largely involve agrometeorology through attempts to optimize the use of fertilizers, pesticides and water for irrigation, three ingredients that are fundamental in order to satisfy the required increase of food production (e.g. Wild 2003). The challenge is to increase the production without further degradation of water resources.

The most documented consequences of agricultural activities around the world concern (i) groundwater salinization (e.g. Prathapar et al. 1997; Stigter et al. 1998; Singh 2000; Spalding et al. 2001; Milnes and Renard 2004; Oren et al. 2004; Darwish et al. 2005; Martinez-Beltran and Manzur 2005; Rengasamy 2006; Stigter et al. 2006a, b, c; Ibrakhimov et al. 2007; Khan 2007), (ii) nitrate contamination (e.g. Custódio 1982; Van Duijvenbooden and Loch 1983; Jacks and Sharma 1983; Spalding and Exner 1993; Hamilton and Helsel 1995; Canter 1997; Stigter et al. 1998; Singh 2000; Böhlke 2002; Di and Cameron 2002; Causapé et al. 2004; Darwish et al. 2005; Jalali 2005; Rajmohan and Elango 2005; Stigter et al. 2006a, b, c; Lorite-Herrera and Jiménez-Espinosa 2008), and (iii) pesticide contamination (e.g. Chilton et al. 1998; Cerejeira et al. 2000; Van Maanen et al. 2001; Batista et al. 2002; Bouman et al. 2002; Cerejeira et al. 2003; Papadopoulou-Mourkidou et al. 2004a, b; Guzzella et al. 2006; Shomar et al. 2006; Silva et al. 2006; Hildebrandt

T. Stigter (✉)
Instituto Superior Técnico, Technical University of Lisbon, Lisbon, Portugal
e-mail: tibor.stigter@ist.utl.pt

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_108,

et al. 2008). The indicated references include general overviews and case studies in developed and developing countries.

Groundwater salinization caused by agricultural practices is a serious problem, particularly in arid and semi-arid regions, and is mainly linked to two phenomena: (a) crop transpiration and soil evaporation, further enhanced by high groundwater levels, irrigation and groundwater recycling, i.e. pumping – irrigation – evapotranspiration – irrigation return flow (Stigter et al. 1998; Spalding et al. 2001; Milnes and Renard 2004; Oren et al. 2004; Darwish et al. 2005; Stigter et al. 2006a, c; Ibrakhimov et al. 2007); (b) seawater intrusion due to overexploitation in coastal areas (Bear et al. 1999; Milnes and Renard 2004; Stigter et al. 2006a, c). Saline soil water inhibits plant growth due to an osmotic effect, which reduces the ability of the plant to take up water, and due to ion excess, which affects the plant cells (Munns 2002). Soil salinity further induces nutritional imbalances in plants (Rengasamy 2006).

According to Rengasamy (2006) salt-affected soils are naturally present in more than 100 countries of the world, where many regions are also affected by irrigation-induced salinization. A report of the Food and Agriculture Organization (FAO) revealed a total global area of salt-affected soils of well over 800 million hectares (Martinez-Beltran and Manzur 2005). The area is expected to expand due to an increasing global population, requiring an increase in food production and water consumption, and due to climate change, responsible for lower rainfall and longer-lasting droughts in many regions of the world (Giorgi 2006; Bates et al. 2008).

The mitigation of groundwater and soil salinization is complex, as it involves a sensitive water and salt balance that is highly variable between regions and that should be addressed through drainage methods and irrigation methods, soil management, and the choice of suitable plant species and varieties. Certain measures may involve both benefits and threats, which should be carefully weighed.

Introducing more efficient irrigation methods such as drip or trickle irrigation is beneficial from a water-saving point of view and reduces the risk of nutrient leaching, but it involves an increased risk of salinisation. For example, in a case study in Lebanon (Darwish et al. 2005) water shortage led to the use of drip irrigation, which resulted in soil degradation due to salinization. To reduce this problem, many farmers switched to sprinkler irrigation, thereby promoting leaching of the salts. Leaching by irrigation in excess of crop water requirements is a frequently applied measure to reduce soil salinity, but is not always successful (e.g. Qadir et al. 2000; Forkutsa et al. 2009).

When combined with subsurface drainage (Qadir et al. 2000; Sharma and Tyagi 2004), the risk of groundwater salinization is reduced. In irrigated arid and semi-arid zones in India, where overall water scarcity and water logging is frequently accompanied by salinity, subsurface drainage is an essential intervention to reclaim the affected lands, but brings along the problem of drainage disposal (Sharma and Tyagi 2004). Other solutions include growing salt-tolerant crops, preferably in combination with leaching. In the latter case irrigation of tolerant crops with saline (drainage) water is followed by irrigation of salt-sensitive crops with non-saline water that simultaneously leaches out the accumulated salts from the previous irrigation (Qadir et al. 2000; Sharma and Tyagi 2004).

Fertilization is the principal source of nitrate contamination on a regional scale (Nolan 2001; Böhlke 2002). Commercial fertilizer nitrogen (N) accounts for approximately half of all N reaching global croplands today and supplies basic food needs for at least 40% of the population (Fixen and West 2002). Global consumption of N fertilizer grew exponentially between 1960 and 1985, followed by a period of relative stabilization, as revealed by data of the International Fertilizer Industry Association (IFA 2009) in Fig. IV.5. Due to the continuous economic expansion of some farming systems in developing countries (Box IV.9), the global application of N fertilizer is currently on the rise again. Ammonia and urea (produced from ammonia) are the most widely supplied N fertilizers.

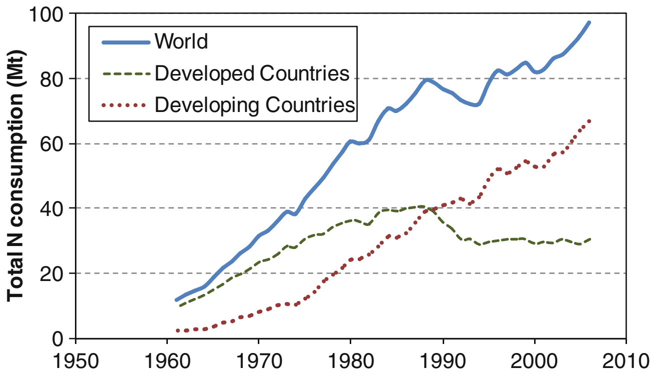


Fig. IV.5 Evolution of N consumption in commercial fertilizers in the world, based on the International Fertilizer Industry Association database used with permission by IFA (2009)

Box IV.9

The application of commercial fertilizers in many developing countries, particularly in Africa and South-America, is limited by unavailability or economic constraints, resulting in soil nutrient losses and a land use efficiency far too low to sustain present and future food production needs (Fixen and West 2002; FAO 2004). Often the only available nitrogen source is manure, with relatively high losses to atmosphere and water, because of its inherent properties (Fixen and West 2002). China and India are currently the largest fertilizer-N consumers in the world. As a result, groundwater contamination by nitrates has occurred in several regions of both countries, overviews of which are given by Li et al. (2007) and Kundu et al. (2008), respectively. The lack of balanced nutrients is one of the causes of contamination, resulting in low fertilizer-N efficiencies. Therefore, improving the nutrient balance as well as the fertilizer product and application practices are promising measures to avoid or reduce the N load on groundwater (Fixen and West 2002, Li et al. 2007). Continued research and educational programs for the farmers in these areas are essential.

The dominant dissolved N compounds in water are nitrate (NO_3^-) and ammonium (NH_4^+). The latter is less mobile, but can be readily transformed into nitrate under aerobic conditions (Kpomblekou and Killorn 1996; Stigter et al. 2006b; Lorite-Herrera and Jiménez-Espinosa 2008). As nitrate neither forms insoluble minerals that could precipitate, nor is significantly adsorbed, denitrification (reduction of nitrate) is the only way for in situ nitrate removal from groundwater, but can only occur in the absence of oxygen and the presence of electron donors such as organic carbon or ferrous iron (Tesoriero et al. 2000; Appelo and Postma 2005).

Groundwater contamination by pesticides can result from their leaching after application due to subsequent rainfall or from inappropriate disposal methods (EEA 1999; WHO 2006). Contamination risk largely depends on pesticide properties, such as solubility, degradation capacity, adsorption capacity and other physicochemical properties of the active substances as well as soil and aquifer characteristics such as permeability, dilution potential, organic matter content, adsorption capacity and the existence of preferential flow (Hallberg 1989; Vighi and Funari 1995; Chilton et al. 1998; Barbash and Resek 1996; Guzzella et al. 2006; Gilliom 2007).

Efforts are being made in many countries to mitigate the problems of surface and groundwater contamination by agricultural practices. In Europe, council Directive 91/676/EEC, known as the Nitrates Directive, was drawn up with the specific purpose to protect waters against pollution caused by nitrates from agricultural sources. Measures include the establishment of codes of good agricultural practice, more carefully balanced fertilization plans and measures to increase N fertilizer efficiency (Box IV.10), as well as detailed groundwater monitoring programs to evaluate the impact of mitigation measures (Goodchild 1998; Stigter et al. 2006b).

Box IV.10

A joint study performed by the United States Department of Agriculture (USDA), IFA, FAO and The Fertilizer Institute (TFI), showed that improved and more precise management practices could result in a reduction of over 20 Mt in the projected N use on all crops for 2030 (Daberkow et al. 2000). As referred by Fixen and West (2002) part of the challenge in all regions of the world is to improve N use efficiency while maintaining or increasing land use efficiency. In other words, crop yields should not be too low (causing low land use efficiency), but should also not be maximized by applying large amounts of N (causing lower N use efficiencies). Producing less than technically possible in order to protect the environment is a relatively new thought in agriculture (Ondersteijn et al. 2002). A promising measure is the limitation of N fertilizer application based on a balance between crop requirements and N supply from soil and irrigation water. For example, a simple calculation will tell us that the annual application of 800 mm (8, 000 m^3 ha^{-1}) of groundwater for irrigation (example for Mediterranean citrus culture), containing 50 mg l^{-1} of nitrate (the WHO consumption limit), results in an annual supply of 90 kg of N, roughly half the required amount (Quelhas dos Santos 1991). Fertilization plans based on soil and irrigation water analyses are gaining interest in Europe (EC 2002), as research is showing that N use efficiencies are not optimal, meaning that the fear of a reduced amount of applied fertilizers affecting the farmers' crop yields, is unwarranted. In fact, according to the EC (2002) significant yield decreases that would result from N application reduction are not reported in the literature.

Many reports mention the lowering of inputs without any yield reduction because of the positive impact of improved practices. de Paz and Ramos (2004) found that N fertilization rates for citriculture in the region of Valencia in Spain could be reduced by 50% to a rate similar to that recommended by the Code of Good Agricultural Practice in the area, without affecting crop yields. In a three-year experiment performed in an area near Madrid, Spain, Diez et al. (1997) showed that different irrigation schedules and fertilizer types (including an unfertilized control plot) did not significantly affect maize grain yields.

Besides a balanced N application, the presence of other macronutrient elements such as potassium (K) and phosphorous (P) in adequate proportions in soil and fertilizer is also very important for N recovery by the crops, as shown in research performed by Johnson et al. (1997) and Schlegel and Havlin (1995), among others (Fixen et al. 2005). The application of K and P commonly has less of a signature in groundwater, since the fate of K is determined in part by ion exchange and sorption, whereas P is sorbed strongly onto solid phases (Böhlke 2002; Oren et al. 2004).

The major factors in North America that have contributed to progress in fertilizer N management are: (i) effective research and development; (ii) education programs for farmers and advisers and (iii) adequate manufacturing, storage, transportation and application practices (Fixen and West 2002). Nevertheless, much remains to be done to further reduce N losses to groundwater, both in Europe and the US.

Nitrate pollution was considered by the European Environment Agency (EEA 2003) as an area of no progress, as the majority of the EU members found it extremely difficult to implement the Nitrates Directive, which suffered severe delays (CEC 1997; CEC 1998; Goodchild 1998; EC 2002; Stigter et al. 2006b). According to Goodchild (1998), the designation of nitrate vulnerable zones (NVZs) and the application of action programs, in compliance with the Nitrates Directive, are strongly hindered by the agricultural lobby, as it fears that the production and consequently the financial situation of many farmers will be seriously affected. In addition, there is often a lack of cooperation and even controversy between the ministries of environment and agriculture, further aggravated by the existence of other N sources such as the infiltration of sewage effluents (Goodchild 1998; Oren et al. 2004; Stigter et al. 2006b) or leachates from landfill sites.

Moreover, there is often a great lack of technical support for farmers with regard to the application of mitigation measures. Here lies one of the major problems of the application of agro-environmental policies. Farmers are often considered largely responsible for nitrate pollution and pesticide pollution, but are frequently not fully aware of the consequences of their practices or lack the knowledge to improve them. In other cases, they lack the economic capacity or will to change the situation. Imposing rigorous measures and applying fines in the case of non-compliance is not the solution and has rarely proven successful, also because the control is often deficient or even nonexistent. Instead, communication and cooperation with the farmers, as well as technical support and training, are key measures for a wide adoption of agro-environmental policies.

References

Appelo CAJ, Postma D (2005) Geochemistry, groundwater and pollution, 2nd edn. Balkema, Leiden, 649pp

Barbash JE, Resek EA (1996) Pesticides in ground water: distribution trends and governing factors. Ann Arbor Press, Chelsea, 588pp

Bates BC, Kundzewicz ZW, Wu S, Palutikof JP (eds) (2008) Climate change and water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210pp

Batista S, Silva E, Galhardo S, Viana P, Cerejeira MJ (2002) Evaluation of pesticide contamination of ground water in two agricultural areas of Portugal. Int J Environ Anal Chem 82:601–609

Bear J, Cheng AH-D, Sorek S, Ouazar D, Herrera I (eds) (1999) Seawater intrusion in coastal aquifers – concepts, methods and practices. Kluwer, Dordrecht, 625pp

Böhlke JK (2002) Groundwater recharge and agricultural contamination. Hydrogeol J 10:153–179

Bouman BAM, Castañeda AR, Bhuiyan SI (2002) Nitrate and pesticide contamination of groundwater under rice-based cropping systems: past and current evidence from the Philippines. Agric Ecosyst Environ 92:185–199

Canter LW (1997) Nitrates in groundwater. Lewis, Boca Raton, 263pp

Causapé J, Quiléz D, Aragüés R (2004) Assessment of irrigation and environmental quality at the hydrological basin level II. Salt and nitrate loads in irrigation return flows. Agric Water Manag 70:211–228

CEC – Commission of the European Communities (1997) Report of the Commission to the Council and European Parliament: the implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources. Report COM(1997) 473, OOPEC, Luxembourg, 18pp

CEC (1998) Report of the Commission to the Council and European Parliament: Measures taken pursuant to council directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources. Summary of reports submitted to the Commission by Member States under Article 11. Report COM(1998) 16, OOPEC, Luxembourg, 37pp

Cerejeira MJ, Silva E, Batista S, Trancoso A, Centeno MSL, Silva-Fernandes A (2000) Simazine metribuzine and nitrates in ground water of agricultural areas of Portugal. Toxicol Environ Chem 75:245–253

Cerejeira MJ, Viana P, Batista S, Pereira T, Silva E, Valério MJ, Silva A, Ferreira M, Silva-Fernandes AM (2003) Pesticides in Portuguese surface and ground waters. Water Res 37: 1055–1063

Chilton PJ, Lawrence AR, Stuart ME (1998) Pesticides in groundwater: some preliminary results from recent research in temperate and tropical environments. In: Mather J, Banks D, Dumpleton S, Fermor M (eds) Groundwater contaminants and their migration. Geological Society, London, Special publications 128:333–345

Custódio E (1982) Nitrate build-up in Catalonia coastal aquifers. Symposium "Impact of Agricultural Activities on Groundwater". Memoires IAH 16:171–181

Daberkow S, Isherwood KF, Poulisse J and Vroomen H (2000) Fertilizer Requirements in 2015 and 2030. Proceedings of the IFA Agricultural Conference on Managing Plant Nutrition, Barcelona, 29 June–2 July 1999, 38pp

Darwish T, Atallah T, El Moujabber M, Khatib N (2005) Salinity evolution and crop response to secondary soil salinity in two agro-climatic zones in Lebanon. Agric Water Manag 78:152–164

de Paz JM, Ramos C (2004) Simulation of nitrate leaching for different nitrogen fertilization rates in a region of Valencia (Spain) using a GIS – GLEAMS system. Agric Ecosyst Environ 103: 59–73

Di HJ, Cameron KC (2002) Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. Nutr Cycl Agroecosys 64:237–256

Diez JA, Roman R, Caballero R, Caballero A (1997) Nitrate leaching from soils under a maize-wheat-maize sequence, two irrigation schedules and three types of fertilizers. Agric Ecosyst Environ 65:189–199

EC (2002) Implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources. Synthesis from Year 2000 Member States Reports, OOPEC, Luxembourg, 44pp

EEA (1999) Groundwater quality and quantity in Europe. European Environmental Agency, Copenhagen, 123pp. http://reports.eea.europa.eu/groundwater07012000/en/enviassrp199903

EEA (2003) Europe's water: an indicator-based assessment. Topic report, EEA, Copenhagen, 97pp

FAO (2004) Fertilizer use by crop in Brazil. Food and Agriculture Organization, Rome, 52pp

Fixen PE, West FB (2002) Nitrogen fertilizers: meeting contemporary challenges. Ambio 31: 169–176

Fixen PE, Jin JY, Tiwari KN, Stauffer MD (2005) Capitalizing on multi-element interactions through balanced nutrition – a pathway to improve nitrogen use efficiency in China, India and North America. Sci China C Life Sci 48:780–790

Forkutsa I, Sommer R, Shirokova YI, Lamers JPA, Kienzler K, Tischbein B, Martius C, Vlek PLG (2009) Modeling irrigated cotton with shallow groundwater in the Aral Sea Basin of Uzbekistan: II. Soil salinity dynamics. Irrig Sci 27:319–330

Gilliom RJ (2007) Pesticides in US streams and groundwater. Environ Sci Tech 41:3408–3414

Giorgi F (2006) Climate change hot-spots. Geophys Res Lett 33:L08707

Goodchild RG (1998) EU Policies for the reduction of nitrogen in water: the example of the Nitrates Directive. Environ Pollut 102:737–740

Guzzella L, Pozzoni F, Giuliano G (2006) Herbicide contamination of surficial groundwater in Northern Italy. Environ Pollut 142:344–353

Hallberg GR (1989) Pesticide pollution of groundwater in the humid United States. Agric Ecosyst Environ 26:299–367

Hamilton PA, Helsel DR (1995) Effects of agriculture on ground-water quality in five regions of the United States. Ground Water 33:217–226

Hildebrandt A, Guillamón M, Lacorte S, Tauler R, Barceló, D (2008) Impact of pesticides used in agriculture and vineyards to surface and groundwater quality (North Spain). Water Res 42:3315–3326

Ibrakhimov M, Khamzina A, Forkutsa I, Paluasheva G, Lamers JPA, Tischbein B, Vlek PLG, Martius C (2007) Groundwater table and salinity: spatial and temporal distribution and influence on soil salinization in Khorezm region (Uzbekistan Aral Sea Basin). Irrigation Drain Syst 21:219–236

IFA (2009) International Fertilizer Industry Association (IFA) database. Accessed with permission at http://www.fertilizer.org/ifa/ifadata/search
Ioffe AF, Revut IB (eds) (1966) Fundamentals of agrophysics. Israel program for scientific translations, Jerusalem, 726pp
Jacks G, Sharma VP (1983) Nitrogen circulation and nitrate in ground water in an agricultural catchment in southern India. Environ Geol 5:61–64
Jalali M (2005) Nitrates leaching from agricultural land in Hamadan, western Iran. Agric Ecosyst Environ 110:210–218
Johnson JW, Murrell TS, Reetz Jr HF (1997) Balanced fertility management: a key to nutrient use efficiency. Better Crops 81:3–5
Khan S (2007) Equivalent cropping area and whole farm water balance approaches to reduce net recharge to shallow saline groundwater from rice based cropping systems. Paddy Water Environ 5:143–152
Kpomblekou AK, Killorn R (1996) Nitrification of ammonium nitrogen in soils treated with XDE-474. Soil Sci Soc Am J 60:1482–1489
Kundu MC, Mandal B, Sarkar D (2008) Assessment of the potential hazards of nitrate contamination in surface and groundwater in a heavily fertilized and intensively cultivated district of India. Environ Monit Assess 146:183–189
Li X, Hu C, Delgado JA, Zhang Y, Ouyang Z (2007) Increased nitrogen use efficiencies as a key mitigation alternative to reduce nitrate leaching in north china plain. Agric Water Manag 89:137–147
Lorite-Herrera M, Jiménez-Espinosa R (2008) Impact of agricultural activity and geologic controls on groundwater quality of the alluvial aquifer of the Guadalquivir River (province of Jaén Spain): a case study. Environ Geol 54:1391–1402
Martinez-Beltran J, Manzur CL (2005) Overview of salinity problems in the world and FAO strategies to address the problem. Proceedings of the International Salinity Forum, Riverside, April, pp 311–313
Milnes E, Renard P (2004) The problem of salt recycling and seawater intrusion in coastal irrigated plains: an example from the Kiti aquifer (Southern Cyprus). J Hydrol 288:327–343
Munns R (2002) Comparative physiology of salt and water stress. Plant Cell Environ 25:239–250
Nolan BT (2001) Relating nitrogen sources and aquifer susceptibility to nitrate in shallow groundwaters of the United States. Groundwater 39:290–299
Ondersteijn CJM, Beldman ACG, Daatselaar CHG, Giesen GWJ, Huirne RBM (2002) The Dutch mineral accounting system and the European Nitrate Directive: implications for N and P management and farm performance. Agric Ecosyst Environ 92:283–296
Oren O, Yechieli Y, Bohlke JK, Dody A (2004) Contamination of groundwater under cultivated fields in an arid environment, central Arava Valley, Israel. J Hydrol 290:312–328
Papadopoulou-Mourkidou E, Karpouzas DG, Patsias J, Kotopoulou A, Milothridou A, Kintzikoglou K, Vlachou P (2004a) The potential of pesticides to contaminate the groundwater resources of the Axios river basin in Macedonia, Northern Greece. Part I. Monitoring study in the north part of the basin. Sci Total Environ 321:127–146
Papadopoulou-Mourkidou E, Karpouzas DG, Patsias J, Kotopoulou A, Milothridou A, Kintzikoglou K, Vlachou P (2004b) The potential of pesticides to contaminate the groundwater resources of the Axios river basin. Part II. Monitoring study in the south part of the basin. Sci Total Environ 321:147–164
Prathapar SA, Meyer WS, Madden JC, Alociljá, E (1997) SWAGMAN options: a hierarchical multicriteria framework to identify profitable land uses that minimize water table rise and salinization. Appl Math Comput 83:217–240
Qadir M, Ghafoor A, Murtaza G (2000) Amelioration strategies for saline soils: a review. Land Degrad Dev 11:501–521
Quelhas dos Santos J (1991) Fertilização-Fundamentos da utilização dos adubos e correctivos [Fertilization-Fundamentals of fertilizer and corrective use]. Francisco Lyon de Castro, Publ Europa-América Lda, Mem Martins, Portugal, 441pp

Rajmohan N, Elango L (2005) Nutrient chemistry of groundwater in an intensively irrigated region of southern India. Environ Geol 47:820–830

Rengasamy P (2006) World salinization with emphasis on Australia. J Exp Biol 57:1017–1023

Rose CW (1966) Agricultural physics. Pergamon Press, Oxford, etc, 226pp

Schlegel AJ and Havlin JL (1995) Corn response to long-term nitrogen and phosphorus fertilization. J Prod Agric 8:181–185

Sharma DP, Tyagi NK (2004) On-farm management of saline drainage water in arid and semi-arid regions. Irrig Drain 53:87–103

Shomar BH, Müller G, Yahya A (2006) Occurrence of pesticides in groundwater and topsoil of the Gaza Strip. Water Air Soil Pollut 171:237–251

Silva E, Batista S, Viana P, Antunes P, Serôdio L, Cardoso AT, Cerejeira MJ (2006) Pesticides and nitrates in groundwater from oriziculture areas of the “Baixo Sado” region (Portugal). Int J Environ Anal Chem 86:955–972

Singh RB (2000) Environmental consequences of agricultural development: a case study from the Green Revolution state of Haryana, India. Agric Ecosyst Environ 82:97–103

Spalding RF, Exner ME (1993) Occurrence of nitrate in groundwater – a review. J Environ Qual 22:392–402

Spalding RF, Watts DG, Schepers JS, Burbach ME, Exner ME, Poreda RJ, Martin GE (2001) Controlling nitrate leaching in irrigated agriculture. J Environ Qual 30:1184–1194

Stigter TY, van Ooijen SPJ, Post VEA, Appelo CAJ, Carvalho Dill AMM (1998) A hydrogeological and hydrochemical explanation of the groundwater composition under irrigated land in a Mediterranean environment: Algarve, Portugal. J Hydrol 208:262–279

Stigter TY, Carvalho Dill AMM, Ribeiro L, Reis E (2006a) Impact of the shift from groundwater to surface water irrigation on aquifer dynamics and hydrochemistry in a semi-arid region in the south of Portugal. Agric Water Manag 85:121–132

Stigter TY, Ribeiro L, Carvalho Dill AMM (2006b) Application of a groundwater quality index as an assessment and communication tool in agro-environmental policies – two Portuguese case studies. J Hydrol 327:578–591

Stigter TY, Ribeiro L, Carvalho Dill AMM (2006c) Evaluation of an intrinsic and a specific vulnerability assessment method in comparison with groundwater salinisation and nitrate contamination levels in two agricultural regions in the south of Portugal. Hydrogeol J 14:79–99

Tesoriero A, Liecscher H, Cox S (2000) Mechanism and rate of denitrification in agricultural watershed: electron and mass balance along ground water flow paths. Water Resour Res 36: 1545–1559

Van Duijvenbooden W, Loch JPG (1983) Nitrate in the Netherlands: a serious threat to groundwater. Aqua 2:59–60

Van Maanen JMS, de Vaan MAJ, Veldstra AWF, Hendrix WPAM (2001) Pesticides and nitrate in groundwater and rainwater in the Province of Limburg in the Netherlands. Environ Monit Assess 72:95–114

Van Wijk WR (ed) (1966) Physics of plant environment, 2nd edn. North Holland Publishing Co, Amsterdam, 382pp

Vighi M, Funari E (1995) Preface. In: Vighi M, Funari E (eds) Pesticide risk in groundwater. CRC Press, Boca Raton, 275pp

WHO (2006) Guidelines for drinking-water quality [electronic resource]: incorporating first addendum Vol 1, Recommendations, 3rd edn. World Health Organization, Geneva, 515pp. http://www.who.int/water_sanitation_health/dwq/gdwq0506.pdf

Wild A (2003) Soils, land and food: managing the land during the twenty-first century. Cambridge University Press, Cambridge, UK, 256pp

IV.9 Field Quantification

Kees Stigter

As an experimental physicist by education, with a PhD in agricultural sciences on a subject in environmental physics (Stigter 1974), in July 1978, after $2^1/_2$ years of associate professorship at the University of Dar es Salaam, I became for more than 6 years a full professor in agricultural physics there (Stigter 1982a). When I left Tanzania as a resident, in 1985, we had reached two kinds of understanding.

Firstly, field quantification in the tropics needed special attention due to the facts that (i) such work had hardly been done in the tropics anyway and either existing equipment had to be made suitable for tropical conditions or suitable equipment had to be designed and (ii) modeling could not yet be an important issue in many cases, due to the inhomogeneity of tropical agricultural field conditions and the absence of reliable basic data. The latter issue is illustrated in Box IV.11 for hydrological models in general. Chapter IV.17 discusses this problem for agrometeorology. Locally, there was no place for studying processes in the tropical environment but studies of phenomena relevant to the local agricultural production environment should be undertaken, often preferably on-farm (Stigter and Weiss 1986).

Box IV.11 (Contributed by Tomáš Orfánus)

By surveying the rainfall/run off modeling literature, it can be realized that a diverse set of methods and models has been introduced in this regard since the 1800s (Fahmi 2006). Hydrological models are usually categorized in three classes. First are the empirical models, such as the unit hydrograph method or "rational method" (Mulvaney 1851) for peak flow prediction, which tell us what happened in the catchment systems, but usually don't tell us why. These models don't need to explain what is behind data, but rather they are intended to describe their observed patterns. Equations involved in empirical

K. Stigter(✉)
Agromet Vision, Bruchem, The Netherlands; Agromet Vision, Bondowoso, Indonesia; Retired from Wageningen University (Wageningen UR), Wageningen, The Netherlands
e-mail: cjstigter@usa.net

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_109,

models are assessed not from the physical processes in the catchment but from analysis of concurrent input and output time series (Solomatine 2005).

Second are the physically based models (PBMs), which are designed in order to reproduce the real physical process of rainfall/runoff transformation, as occurring in nature. The PBMs are either conceptually lumped models (e.g. Bergström and Forsman 1973) or distributed models (e.g. Beven 1997). The former operate with mutually interrelated storages, representing physical elements in the catchment, and the latter uses basic mathematical representations of the flows of mass and energy. Parameters of conceptual models, unlike the physically based ones, usually cannot be determined directly from physical catchments characteristics, and hence their values must be estimated by calibration against observed data.

The third class are the stochastic system models, which create a black box mapping from rainfall and/or previous runoff sequences to current runoff (e.g. Box et al. 1994).

During the last decades "mathematical modeling" has become an Alfa and Omega of most hydrological studies. Regrettably, it usually means sterile manipulations of numbers, based neither on serious data nor on adequate theory, but promising great "from the table"-solutions of any physical problem in the hydrosphere, however complex it is. Thus, hydrological models make an ideal tool for the preservation and spreading of hydrologic misconceptions (Klemeš 2000).

One typical example well accommodated in hydrology is the extrapolation of flood frequency curves. From an empirical point of view a 2- or 5-year flood may be a sound concept on the assumption that 50 years or so of data are available, if the historic record does not look conspicuously different from a random series, and physical conditions during that period are known to have been approximately stationary. However to extrapolate this empirical concept to, say, a 10,000-year flood does not make sense for most rivers in the northern hemisphere (Klemeš 2000). The concept of average return period can often hardly be justified even beyond a 10-year flood or so, because of non-stationarity of physical conditions over periods longer then 50–100 years.

Actually, at present any extrapolations of what happens in say 10 years periods is made problematic because of climate change itself. Also what we want to learn from the past in response farming must be limited to shorter periods because of climate change itself (Stigter 2008). The danger of extrapolation of wrong patterns increases with a diminishing possibility of checking the results by observation. It is therefore in this direction in which the need for a sound scientific basis of hydrologic models increases. Unfortunately, this is the same order in which also the difficulty of the problem increases and our understanding of relevant physical mechanisms decreases.

It seems obvious that the search for the new measurement methods and models that would yield areal distribution, or at least reliable areal totals or averages, of hydrologic variables such as precipitation, evapotranspiration (e.g. Allen 1996; Allen et al. 2006), and soil moisture would be a much better investment for hydrology. Maps created using remote sensing based processing systems may some day be routinely used as input to daily and monthly operational and planning models for reservoir operations, groundwater management, irrigation water supply planning, water rights regulation, and hydrologic studies.

Secondly, to assist farmers in decision making, little could be learned from the situation in developed countries, because in the early eighties management oriented weather services were generally not available to farmers there, while any advisories available had little practical utility and therefore were not often incorporated into the management decision making processes there (Stigter 1984). This conclusion meant that agrometeorology had to look at the local agricultural extension situation for contact with farmers.

However, by the early 1980s, if anything there was a top-down structure along which little useful information would reach farmers, their conditions were not understood at all and the extension approach, if any, was one of "modernization", completely out of tune with the reality of agricultural production of peasant farming. Peasants were seen as backwards and uneducated. As a countermovement, in the seventies genuine interest was shown in indigenous knowledge in use and traditional techniques developed by peasant communities. We were the first to work into that direction in agricultural meteorology (e.g. Stigter 1983, 1987; see also Sect. I.5.2 in Part I of this book).

As to the first point of the first issue above, we will first exemplify this for routine quantification for agrometeorology. Box IV.12 deals with this subject in general. But for the tropics adaptations often need to be made to equipment, corrections have to be applied or certain instruments and/or parameterizations have to be preferred above others. In Dar es Salaam, in addition to numerous educational exercises and improvements, we particularly dealt with very many issues related to equipment measuring solar radiation components under tropical conditions, as reviewed in Stigter et al. (1989); with cloudiness issues in the lower latitudes (e.g. Stigter 1982b); with developing the shaded Piche evaporimeter as an ancillary anemometer in the tropics (Stigter and Uiso 1981; Kainkwa and Stigter 2000; Stigter et al. 2005a), also preparing its use as a replacement of the aerodynamic term in the Penman equation (Ibrahim et al. 1989); with errors in routine air humidity data (Stigter and Weiss 1986), with conservative photosynthetically active radiation percentages (Stigter and Musabilha 1982) and with parameterization (e.g. Stigter 1977; 1994b) and quantification (e.g. Stigter 1978) of reference crop evaporation.

Box IV.12 (Contributed by Raymond P. Motha)

Manually observed station data mainly form the basis of agrometeorological information not only in the research but also in the operative use. While the system of manually observed meteorological data collection is well established and standardized, the definitions of agrometeorological data are not very specific (e.g. Murthy et al. 2010). Though the methodologies of agronomic data observation are quite well defined from the academic point of view, the practice varies greatly even on the regional level, based on crop variety and species. Observations are generally planting dates, key stages of crop development, and harvest. Plant height and crop water stress conditions may be observed for selective crops and situations.

The following are some basic considerations for agronomic measurements: observations are from a plant community and not single plants; there are much more descriptive elements in the observation; the frequency of the observation is different and can vary during the growing season; in Europe (WMO 1988), up to 40% of collected phenological data is compiled and used operationally; 30% of countries collecting phenological data do not include it in their database. The collection of manually observed data is highly time-consuming with transmission done by a variety of methods and frequencies.

The implementation of the WMO CLIme COMputing (CLICOM) project (http://www.gsf.de/UNEP/wcdmp.html) has afforded many countries a much higher level of data processing and data control. Automatic weather station (AWS) data are becoming the alternative method for collection of climate and agrometeorological data in many countries, and are a necessity for many real-time operational programs (Hubbard and Sivakumar 2001). The data are now automatically collected from electronic media and automatically transmitted over the radio or telephone systems. The initial cost is high to establish the network but, in the long run, they are a more efficient method for simplified data processing and archiving. This technology continues to evolve and the decline in costs makes it more feasible in more developing countries, especially with donor funding for initial initiation and training. The maintenance of these stations requires a lot more technical skills, however, and this at present still gives serious problems in developing countries (e.g. Stigter 2007).

Remotely sensed data and AWS systems provide, in many ways, an enhanced and very feasible alternative to manual observation for a very short time span between data collection and transmission. The remote sensing methods of data collection are based on measurement of reflected (short-wave) and emitted (thermal) electromagnetic radiation from the surface of the earth. The data processing can be rigorous, however. Most processing software is standardized for retrieval of basic information that is useful for agrometeorological applications. Proper calibration and atmospheric correction of imagery data are still major concerns in data processing, especially for application in retrieval of crop growth parameters.

In certain countries where only few stations are in operation, as in northern Turkmenistan (Seitnazarov quoted by Doraiswamy et al. 2000), remotely sensed data can improve information on crop conditions for an early warning system (EWS). Geostationary Orbiting Environmental Satellites (GOES) can measure frequent surface temperature, solar radiation (cloud cover) and relative rainfall. Unlike the polar orbiting satellites, the GOES satellites can provide continuous monitoring of the Earth's atmosphere and surface over a large region of the western hemisphere in a geosynchronous orbit. These satellites monitor potential severe weather conditions, such as tornadoes, flash floods, hail storms, and hurricanes.

Later experimental field work in Dar es Salaam evolved around mulching as a technique of microclimate management and manipulation, as partly reviewed in Stigter (1994a). Quantification of mulch parameters included the use of an infrared thermometer improved for use under tropical conditions, adapted soil temperature equipment, and tube solarimeters for radiation extinction determinations in mulches (Stigter 1994a). Errors for low latitude conditions in the latter were traced and in the course of time taken care of (Mungai et al. 1997). This was also a start for later field quantification of more microclimatic management and manipulation issues (e.g. Stigter and Darnhofer 1989).

As to that same first point in the second paragraph above, I was able to mount the Dutch Government funded TTMI-project, as explained in Sect. I.3.3 of Part I, in which project we practised this approach of field quantification of relevant phenomena in the agricultural production environment, in a setting of research education (Mungai et al. 1996; Stigter et al. 1998a; Stigter and Ng'ang'a 2001). Sometimes we were able to capitalize on earlier quantification developments as discussed above, such as using the shaded Piche evaporimeter for interpolation and extrapolation purposes in agroforestry wind observations in four countries (Stigter et al. 1998b; 2000) and in some of the other agroforestry quantification work in Kenya (Mungai et al. 1997; 2000).

Sometimes equipment had again to be specially designed, like in the case of the shaded Piche evaporimeter, or had to be adapted from unsuitable commercial items (e.g. Coulson et al. 1988; 1989), such as in the quantification of wind blown saltating and creeping sand (Mohammed et al. 1996; Al-Amin 1999), of moisture contents in stored grain (Abdalla et al. 2001) and of soil evaporation and run off and soil loss in agroforestry conditions (Kinama et al. 2005; 2007). Sometimes the tropical conditions demanded very special precautions to prevent mis-interpretations (e.g. Coulson et al. 1988) or their inhomogeneity demanded the design and development of sampling adaptations (e.g. Ibrahim et al. 1999; Oteng'i et al. 2000; Oluwasemire et al. 2002).

The above exemplified field quantifications only served one kind of purposes: Designing solutions to farmers' problems (e.g. Stigter et al. 2005a). Beforehand, in the three/four African countries of the TTMI-Project, in 1985/1986 and in 1991/1992 priority problems of farmers were identified with these farmers by the Universities and local Institutes we worked with and/or with the international organizations with which we collaborated, particularly in Kenya.

The choices made this way guaranteed that we were addressing actual priority problems (see also Box I.1 in Part I), related to five themes: (i) protection from wind (in Tanzania and Kenya) and wind blown sand (Sudan) and heat carried by dry air (Nigeria), all in agroforestry settings, (ii) water waste in irrigation (Sudan), (iii) traditional storage conditions of grain (Sudan, Tanzania), (iv) introduction of alley cropping agroforestry on flat and sloping land (both Kenya) and (v) improvement of traditional millet intercropping systems (Nigeria).

The results in relation to agrometeorological services rendered were widely used and published, also in connection with our research polices explained above (e.g. Stigter 2005b, c, d, e; Stigter 2006). As can be seen from Stigter (2005b, d, e) and Stigter et al. (2007), in our programmes and visits, between 1997 and the present, in China, Indonesia and Vietnam, we used the African experience in taking part in existing research education exercises there, on the outcome of which we reported and still report in comparison with the African results. We also made some projections for an African future (Stigter et al. 2005f).

A big difference with the African work described above is, however, the actual quantifications taking place. One may first observe from the contents of the journal Agricultural and Forest Meteorology, of which editorial board I am a member since 1985, that in agricultural meteorology, field quantification is particularly still taking place in regard to studying processes. That is the main stream research in agricultural meteorology.

The quantification of phenomena in the agricultural production environment has become much less important in the western world, largely due to simulation modeling applications. It is still larger related to water and climate than related to meteorology, as confirmed by a large manufacturer of equipment (Eijkelkamp, Giesbeek, Netherlands, personal communication 2008). In developing countries quantification in agricultural meteorology has remained negligible. One difficulty is that the quantification should of course change compared to what we did say 50 years ago.

A connection with actual farmers' problems is in the scarce field research often missing. Such problems are presently mainly addressed by NGOs in participatory approaches in which field quantifications play only a very modest role, with the exception of on-farm rainfall observations. As we have shown in Part II of this book, agrometeorological services can gain a lot from quantitative field research supporting design and understanding of improved services (e.g. Stigter et al. 2005a, see also WMO 2010). In China this idea is slowly winning support, but no results are communicated; in India, Vietnam and South Africa there are possibilities for the advance of such approaches. See Parts II and III.

References

Abdalla AT, Stigter CJ, Mohamed HA, Mohammed AE, Gough MC (2001) Effects of wall linings on moisture ingress into traditional grain storage pits. Int J Biometeorol 45:75–80

Al-Amin NKN (1999) The physical potential of indigenous vegetation and other means to suppress sand movement in a secondary desertification source area near the White Nile in Gezira region (Sudan). Unpublished Ph.D. thesis. University of Gezira. Wad-Medani. Sudan, XVI + 413pp

Allen RG (1996) Assessing integrity of weather data for use in reference evapotranspiration estimation. J Irrig Drain Eng ASCE 122:97–106

Allen RG, Pruitt WO, Wright JL, Howell TA, Ventura F, Snyder R, Itenfisu D, Steduto P, Berengena J, Yrisarry JB, Smith M, Pereira LS, Raes D, Perrier A, Alves I, Walter I, Elliott R (2006) A recommendation on standardized surface resistance for hourly calculation of reference ETo by the FAO56 Penman-Monteith method. Agric Water Manag 81:1–22

Bergström S, Forsman A (1973) Development of a conceptual deterministic rainfall-runoff model. Nordic Hydrol 4(3): 147–170

Beven KJ (1997) TOPMODEL user notes (Windows version). Centre for Research on Environmental Systems and Statistics, Lancaster University, Lancashire, no cons page.

Box GEP, Jenkins GM, Reinse GC (1994) Time series analysis, forecasting and control, 3rd edn. Prentice Hall, Englewood Clifs, 350pp

Coulson CL, Stigter CJ (1988) Appropriateness of instrumentation for agro-ecological research in low-income developing countries. Funct Ecol 2:109–113

Coulson CL, Stigter CJ (1989) Appropriateness of instrumentation in agroforestry research in developing countries. In: Reifsnyder WE, Darnhofer T (eds) Meteorology and agroforestry. Proceedings of an ICRAF/WMO/UNEP Workshop on Application of Meteorology in Agroforestry Systems Planning and Management, ICRAF, Nairobi, pp 305–314

Coulson CL, Stigter CJ, Akunda E, Floor-Drees E (1988). Instrument based distortions of leaf/air temperature differences and interpretations of bean drought stress resistance. J Trop Agric 65:352–354

Doraiswamy PC, Pasteris PA, Jones KC, Motha RP, Nejedlik P (2000) Techniques for methods of collection, database management and distribution of agrometeorological data. Agric For Meteorol 103:83–97

Fahmi AH (2006) Estimation of rainfall-runoff model parameters using optimization techniques. International Symposium on Water and Land Management for Sustainable Irrigated Agriculture. Proceedings edited and published by Cukurova University, Adana, Turkey, no cons page

Hubbard K, Sivakumar MVK (eds) (2001) Automated weather stations for applications in agriculture and water resources management: current and future perspectives. Proceedings of an International Workshop, Lincoln, March 2000. High Plains Climate Center, Lincoln; WMO, Geneva, 370pp

Ibrahim AA, Stigter CJ, Adeeb AM, Adam HS, Jansen AE (1989) Development and validation of a shaded Piche evaporimeter for the tropics to replace humidity and wind speed data in the aerodynamic term of the Penman equation. Proceedings of the 4th Technical Conference on Instruments and Methods of Observation (TECIMO IV), Instruments and Observing Methods Report No. 35, WMO/TD No. 303_r, Geneva, pp 147–152

Ibrahim AA, Stigter CJ, Adeeb AM, Adam HS, Van Rheenen W (1999) On-farm sampling density and correction requirements for soil moisture determination in irrigated heavy clay soils in the Gezira, Central Sudan. Agric Water Manag 41:91–113

Kainkwa RMR, Stigter CJ (2000) Measuring wind gradients in agroforestry systems by shaded Piche evaporimeters I. Validation of the square-root dependence on wind speed. Intern Agrophys 14:279–289

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2005) Evaporation from soils below sparse crops in contour hedgerow agroforestry in semi-arid Kenya. Agric For Meteorol 130:149–162

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2007) Contour hedgerows and grass strips for erosion and runoff control in semi-arid Kenya. Arid Land Res Manag 21:1–19

Klemeš V (2000) Common sense and other heresies. In: Sellars CD (ed) Selected papers on hydrology and water resources engineering. Canadian Water Resources Association, Cambridge, Canada, 378pp

Mohammed AE, van de Veer OD, Oldenziel HJ, Stigter CJ (1996) Wind tunnel and field testing of a simple sand catcher for sampling inhomogeneously saltating sand in desertified environments. Sedimentology 43:497–503

Mulvaney TJ (1851) On the use of self-registering rainfall and flood gauges in making observations on the relation of rainfall and of flood discharges in a given catchment. Trans Inst Civ Eng Ireland 4(2): 18–31

Mungai DN, Stigter CJ, Ng'ang'a JK, Coulson CL (1996) New approach in research education to solve problems of dryland farming in Africa. Arid Soil Res Rehabil 10: 169–177

Mungai DN, Stigter CJ, Coulson CL, Ng'etich WK, Muniafu MM, Kainkwa RMR (1997) Measuring solar radiation transmission in tropical agriculture using tube solarimeters. A warning. Agric For Meteorol 86:235–243

Mungai DN, Stigter CJ, Coulson CL, Ng'ang'a JK (2000) Simply obtained global radiation, soil temperature and soil moisture in an alley cropping system in semi-arid Kenya. Theor Appl Clim 65:63–78

Murthy VRK, Milford J, Stigter K, Orlandini S, Oliphant A, Grant R, Wieringa J (2010) Agricultural meteorological elements and their observations. Chapter 2 In: Guide to agricultural meteorological practices, 3rd edn. WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]

Oluwasemire KO, Stigter CJ, Owonubi JJ, Jagtap SS (2002) Seasonal water use and water yield of millet based cropping systems in the Nigerian Sudan Savanna near Kano. Agric Water Manag 56:207–227

Oteng'i SBB, Stigter CJ, Ng'ang'a JK, Mungai DN (2000) Wind protection in a hedged agroforestry system in semi-arid Kenya. Agrofor Syst 50:137–156

Solomatine DP (2005) Data-driven modeling and computational intelligence methods in hydrology. In: Anderson MG (ed) Encyclopedia of hydrological sciences. Wiley, Chichester, pp 293–306

Stigter (1974) The epidermal resistance to diffusion of water vapour: an improved measuring method and field results in Indian corn (Zea mays L.). Dr. Agr. Sc. Thesis, Wageningen Agricultural University and Agric Res Rep 831:1–25. To this thesis belonged: (i) Stigter CJ (1972) Leaf diffusion resistance to water vapour and its direct measurement. I. Introduction and review concerning relevant factors and methods. Meded Landb Hogesch Wageningen 72(3):1–47. (ii) Stigter CJ, Birnie J, Lammers B (1973) Leaf diffusion resistance to water vapour and its direct measurement. II. Design, calibration and pertinent theory of an improved leaf diffusion resistance meter. Meded Landb Hogesch Wageningen 73(15):1–55. (iii) Stigter CJ, Lammers B (1974) Leaf diffusion resistance to water vapour and its direct measurement. III. Results regarding the improved diffusion porometer in growth rooms and fields of Indian corn (Zea mays L.). Meded Landb Hogesch Wageningen 74(21):1–77

Stigter CJ (1977) Penman again! Clearing up some misconceptions in East African and related literature. Accepted paper prepared for the 6th specialists meeting on applied meteorology, Nairobi, 13pp

Stigter CJ (1978) Reference crop evaporation in Tanzania. East Afr Agric For J 44(2):112–118

Stigter CJ (1982a) Environmental physics, agricultural research and development. Inaugural Lecture Series, No. 30. Dar es Salaam University Press, Tanzania, 54pp

Stigter CJ (1982b) Sampling and estimation of better defined cloudiness for Dar es Salaam. Solar Ene 28(1):49–53

Stigter CJ (1983) Microclimate management and manipulation in traditional farming. Document 15, item "Land use and agricultural management systems under severe climatic conditions". In: Official Report, Commission for Agricultural Meteorology, VIIIth session, 21/2 – 4/3 1983, WMO, Geneva

Stigter CJ (1984) Forecasting and weather services for agriculture in Africa. In: Hawskworth DL (ed) Advancement of agricultural production in Africa. Proceedings of the Commonwealth Agricultural Bureau First Scientific Conference, Arusha. CAB, Farnham Royal, pp 327–331
Stigter CJ (1987) Tapping into traditional knowledge. In: AFRICAN REVIVAL. Rediscovering their own resources. (Centrepiece papers). CERES, The FAO-Review 20(3):29–32
Stigter CJ (1994a) Management and manipulation of microclimate. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 273–284
Stigter CJ (1994b) Micrometeorology. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 59–72
Stigter K (2006) Scientific research in Africa in the 21st century, in need of a change of approach. Afr J Agric Res 1:4–8
Stigter K (2007) An account of visiting those involved in climate field schools in Indonesia. Available at the INSAM website (www.agrometeorology.org) under "Accounts of Operational Agrometeorology". Also used as Appendix II in Stigter K (2008) Coping with climate risks in agriculture needs farmer oriented research and extension policies (based on participation, preparedness and resilience). Paper Presented at the First Venezuelan Agrometeorology Congress, San Cristobal, November 2007. Scientia Agricola (Piracicaba, Brazil), 65(special issue), pp 108–115. http://www.scielo.br/pdf/sa/v65nspe/a16v65nsp.pdf
Stigter K (2008) Agrometeorological services under a changing climate: old wine in new bags. WMO Bull 57(2):114–117
Stigter CJ, Uiso CBS (1981) Understanding the Piche evaporimeter as a simple integrating mass transfer meter. Appl Scient Res 37(3/4):213–224
Stigter CJ, Musabilha VMM (1982) The conservative ratio of photosynthetically active to total radiation in the tropics. J Appl Ecol 19:853–858
Stigter CJ, Weiss A (1986) In quest of tropical micrometeorology for on-farm weather advisories. A guest editorial. Agric For Meteorol 36:289–296
Stigter CJ, Darnhofer T (1989) Quantification of microclimate near the soil surface. Appendix F. In: Anderson JM, Ingram JSI (eds) Tropical soil biology and fertility: a handbook of methods. IUBS/UNESCO (MAB), C.A.B. International, Wallingford, pp 144–157
Stigter CJ, Ng'ang'a JK (2001) Traditional techniques of microclimate improvement African network (TTMI/AN) Project for Research Training. Successful Research Training Partnership Case Study for GFAR-2000, Global Forum on Agricultural Research, Rome. Available on CD-ROM from FAO
Stigter CJ, Hyera TM, Mjungu YB (1986) Accuracies of humidity data from Tanzanian stations and their implications for evaporation calculations. East Afr Agric For J 51(3):131–140
Stigter CJ, Jiwaji NT, Kainkwa RMR, Juma F, Musabilha VMM, Mabuba KI, Waryoba JM (1989) The national radiation measurement and calibration centre in Dar as Salaam, Tanzania: an appraisal of the early work. Proceedings of the 4th Technical Conference on Instruments and Methods of Observation (TECIMO IV), Instruments and Observing Methods Report 35, WMO/TD 303, Geneva, pp 371–376
Stigter CJ, Van den Bor W, Daane JRV, Adam HS, Mohammed AE, Ng'ang'a JK, Mungai, DN (1998a) The "picnic" model for research training at African Universities: evaluation and preliminary comparison. J Agric Educ Ext 5:23–38
Stigter CJ, Kainkwa RMR, Oteng'i SBB, Ibrahim AA, Mohammed AE, Onyewotu LOZ (1998b) The shaded Piche evaporimeter as an ancillary isothermal anemometer. Instruments and Observing Methods Report 70, WMO/TD 877, Geneva, pp 377–380
Stigter CJ, Kainkwa RMR, Oteng'i SBS, Onyewotu LOZ, Mohammed AE, Ibrahim AA, Rashidi MGM (2000) Measuring wind gradients in agroforestry systems by shaded Piche evaporimeters II. Accuracies obtained in some African case studies. Intern Agrophys 14:457–468
Stigter K (CJ), Oteng'i S, Al-Amin NKN, Onyewotu L, Kainkwa R (2005a) Wind protection designs from measurements with simple wind equipment in four African countries in research education capacity building projects. Paper 4.1 in WMO Technical Conference on Meteorolog-

ical and Environmental Instruments and Methods of Observation (TECO-2005). Instruments and Observing Methods – Report No. 82, WMO/TD-No. 1265, WMO, Geneva, 7pp. [Also available on CD-ROM]
Stigter K (CJ), Kinama J, Zhang Yingcui, Oluwasemire T (KO), Zheng Dawei, Al-Amin NKN, Abdalla AT (2005b) Agrometeorological services and information for decision-making: some examples from Africa and China. J Agric Meteorol (Jpn) 60:327–330
Stigter CJ, Oteng'i SBB, Oluwasemire KO, Al-amin NKN, Kinama JM, Onyewotu LOZ (2005c) Recent answers to farmland degradation illustrated by case studies from African farming systems. Ann Arid Zone 44(3):255–276
Stigter K, Oluwasemire T, Onyewotu L, Rashidi AGM, Oteng'i S, Murthy VRK, Van Viet N, Koesmaryono Y, Bakheit NI (2005d) Weather Services making a difference for poor farmers. I. Why it does not happen. Paper Prepared for a Roving Seminar "Agrometeorological Services: Theory and Practice" Given by Kees Stigter in Full in Iran (November 2005), South Africa (February 2008) and Indonesia (March 2009). PowerPoint and paper versions are made available to participants
Stigter K, Oluwasemire T, Onyewotu L, Oteng'i S, Kinama J, Zheng Dawei, Zhao Caixia, Zhang Yingcui, Murthy VRK, Rashidi AGM, Abdalla AT, Al-amin NKN, Bakheit NI (2005e) Weather services making a difference for poor farmers. II. How it can be done. Paper Prepared for a Roving Seminar "Agrometeorological Services: Theory and Practice" Given by Kees Stigter in Full in Iran (November 2005), South Africa (February 2008) and Indonesia (March 2009). PowerPoint and paper versions are made available to participants
Stigter CJ, Onyewotu LOZ, Al-Amin NKN (2005f) Wind and agriculture; an essential subject of the African Participatory Research Agenda. Paper #103 in: Naprstek J, Fischer C (eds) Proceedings of the Fourth European & African Conference on Wind Engineering, ITAMAS, Prague, 11pp. Available on CD-ROM. [Also in Book of Extended Abstracts, pp 306–307]
Stigter CJ, Tan Ying, Das HP, Zheng Dawei, Rivero Vega RE, Nguyen van Viet, Bakheit NI, Abdullahi YM (2007) Complying with farmers' conditions and needs using new weather and climate information approaches and technologies. In: Sivakumar MVK, Motha R (eds) Managing weather and climate risks in agriculture. Springer, Berlin/Heidelberg/New York, pp 171–190
WMO (1988) RA-V Working Group on Agricultural Meteorology. CAgM Report No. 31. Part I: Agrometeorology of the Potato Crop, Part II: Survey of Available Information and Techniques on Operational Agro-meteorological Services for Plant Protection, Part III: Crop Protection Models, WMO/TD 239, Geneva, 151pp
WMO (2010) Agrometeorological services: reaching all farmers with operational information products in new educational commitments. WMO Brochure prepared by CJ Stigter, WMO, Geneva, in press

IV.10 Statistics and Agrometeorology: Introductory Issues and Cases

Roger Stern

This chapter is problem-based, and hence starts with examples of problems. We then look at the climatic data and the statistical methods that are needed to solve the problems.

In Problem 1, an association of cotton growers in West Africa approached the researcher responsible for cotton with a problem. Because of the climate change that they had perceived, they now planted their cotton earlier than before. But this meant that the crop was ready for harvest in late September. Sometimes the change was not as they had hoped, so there was too much rain at harvest time and the crop suffered.

To address this problem, the researcher contacted the NMHS and asked for historical rainfall data for a set of stations for as many years as possible. The Service supplied the data. The researcher knew that some sort of "risk analysis" was needed, but had no experience in processing this type of data. He was an experienced experimenter, so instead he designed a planting date trial, on the research station, with 6 different planting dates and 4 replicates, so 24 plots. He ran this experiment for 3 years.

In Problem 2, researchers in India needed to know how their research needed to adapt given the important issues related to climate change. They designed a survey where they asked farmers about their perceptions of climate change. Figure IV.6 shows some results.

Global warming is an accepted fact and this is consistent with the farmer's unanimity that temperatures had increased. There was however also a unanimous view that rainfall had decreased and was now more erratic. In many places the evidence, from the historical data, for changes in rainfall are not as clear as may be felt by the farmers.

R. Stern (✉)
Statistical Services Centre (SSC), University of Reading, Reading, UK
e-mail: r.d.stern@reading.ac.uk

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_110,

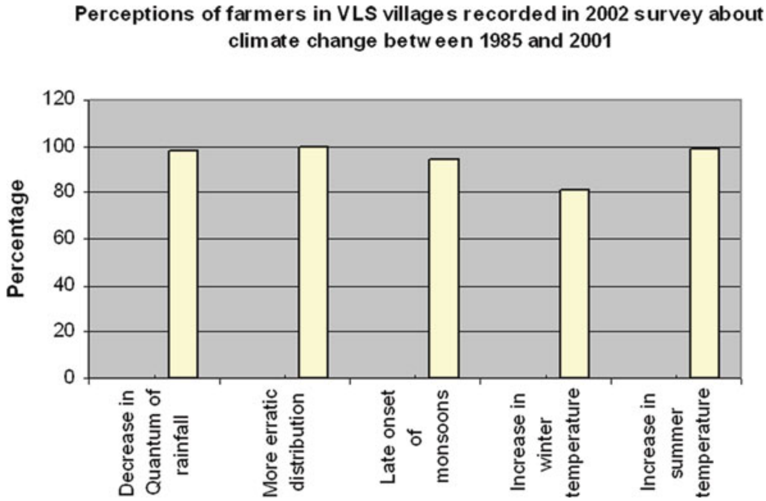


Fig. IV.6 Farmers views on climate change

In Problem 3, farmers were emigrating from southern Zambia, citing climate change as the reason they could no longer farm as they used to. An NGO (Conservation Farming Unit, CFU) was of the view that non-sustainable farming practices were more of a problem than the climate change. With support from FAO, they commissioned a small study of the climatic data to quantify the extent of climate change in relation to the current farming practices at a number of sites in southern Zambia. Results are shown for one of these sites, called Moorings.

A related problem for the CFU was that their recommended practices were to plant as early as possible in the cropping season. However, very early planting ran the risk of long dry spells just after sowing, and hence require a second planting. So they also needed a quantification of the risks of a long dry spell at the start of the season, for different possible planting dates.

Statistics is defined in different ways. The Royal Statistical Society (RSS) offers the following two definitions. First:

- Statistics changes numbers into information, that emphasises the use of the data, once it is available.

The second definition of the RSS covers the whole process from collection to action:

- Statistics is the art and science of deciding:

1. What are the appropriate data to collect
2. and how to collect them efficiently
3. and then using them to give information,
4. answer questions,

5. draw inferences
6. and make decisions.

Wikipedia (when this article was written) said:

- Statistics is a mathematical science pertaining to the collection, analysis, interpretation or explanation, and presentation of data.

Finally, Peck et al. (2006) offers:

- Statistics is the science of learning from data.

When analysing climatic data, why is a single year of data usually insufficient? The problem is that the rainfall (with the other climatic elements) is variable, i.e. it varies from year to year and an analysis of the climatic data must "fight the curse of variation". Peck et al. (2006) state:

- The science of statistics provides tools for dealing with variation.

There are two main strategies for overcoming variation. The first is to take enough observations so the extent of the variation can be quantified. With historical climatic data this usually means obtaining a record for enough years.

The second way to fight the curse of variation is to measure additional characteristics that explain the variation. For example, in Problem 3, in southern Zambia, suppose the pattern of rainfall was related to whether the year was El Nino, or to Sea Surface Temperatures. Then these characteristics help explain the rainfall variability and would therefore help in the analysis.

Three types of study are often distinguished that lead to data for analysis. Data may arise from an experiment, from a survey, or from routine data collection. Climatic data are mainly of this third type, but each type is briefly explained, to put the processing of climatic data into context.

An experiment is where the scientist has some control over the situation, such as the planting date trial in Problem 1. In other experiments, the researcher might dictate which varieties are used. The aspects over which the researcher exercises control are often called the "treatments". The researcher starts by identifying the objectives of the study. These lead to the three components of the experiment, namely which treatments are to be applied, what is the layout (perhaps in blocks on a research farm), and what is to be measured.

So, in a study where success is the highest yield, then obviously the yields must be measured. A survey, such as Problem 2, starts with the objectives, but there are no treatments to apply. The researcher decides the layout (for example a stratified survey in 40 villages) and the measurements to take. In a survey, the farmers might use the same planting dates as in an experiment, but which farmer used which date was their decision, rather than being dictated by the researcher.

In studies using routine data that require historical climatic data, data are originally collected without a specific objective. Scientists can request the data and specify the objectives of an analysis, but are limited in what is possible, because they have no control over what was measured, or of the "layout", i.e. where the data are from. For example, in Problem 3, the main objective is concerned with climate change. This study is only possible if reliable data exist for a sufficiently long record, for stations in southern Zambia. Furthermore the stations with data need to be sufficiently close for the conclusions from the analysis to apply to the farmers of the region.

Finally, in this section, the unit of measurement is considered. For example, in the survey, Problem 2, the main unit was the person answering the questions. In an experiment the main unit is often the plot, on which the yields are measured. Sometimes there may be more than one unit of measurement. For example, a survey in 25 villages may collect some information from, say 500 households within the villages, while other information, like the distance to water, or presence of an extension officer, is collected at the village level. With climatic data the unit of measurement is often daily. For example, in Problem 3, rainfall data were collected each day since 1922, in one site in Zambia. In some stations the measurements may be more frequent, e.g. hourly, but then they are often still available at a daily level.

It is important to have well-defined objectives to be able to do good statistics. These objectives are given at the start of the study when the activity is a survey or an experiment, and dictate the data to be collected. Once the data are available it is useful to review the objectives, and specify the objectives of the analysis. This is because the data collection may show that some objectives are no longer possible, or some new ones have become apparent. With the analysis of climatic data, the data are already available. Hence we start at this second stage and specify the objectives of the analysis. They must be specified in detail, because that will dictate which data to request.

Most NMHSs have an agrometeorology section and also staff with some statistical skills at individual stations. So potential agricultural users, rather than just requesting data, might request a partnership. If so, the earlier partnership is discussed, the more fruitful it is likely to be. Sometimes the partnership can be in the opposite direction, with NMHS staff requesting partners from NGOs, or from agricultural research. In Problem 1, on the optimal planting date for cotton, the agricultural research staff had no experience in conducting a "risk analysis" and hence had done a field experiment. The staff from the NMHS who supplied the climatic data, were able (if asked) to do the "risk analysis". Sadly, they were not asked.

In this section we assume the data in the units as measured are available for the intended study. This is usually daily data. The first step, in the data processing, is usually to transform the data from the units of measurement into the units for analysis. For Problem 3, on climate change in southern Zambia, it was agreed that this should be a study of rainfall data and daily rainfall data were requested for stations with a long record. They were for three stations, with one record from 1922 and two other records starting from the early 1950 s. There were hardly any missing values. One issue concerned the date of first planting. One record was from a privately owned farm and discussions with the owner clarified the criterion used there for planting maize. A simple definition was that planting would be:

- the first occasion, from 15 November, that the 3-day rainfall total exceeded 20 mm.

The first step of organizing the data was therefore to find this date, for each year of the record. This is a transformation of the data from values on a daily basis to one value per year. Hence the units as measured are on a daily basis, while the units for analysis are on a yearly basis.

The daily data usually provide more than one variable for analysis. In this case, the NGO who posed the problem also promoted a simple method of rainwater harvesting. This would increase the length of dry spell that a seedling could withstand, after planting. Hence a second variable was the length of the longest dry spell in the 30 days following planting.

Further variables were to investigate evidence for climate change, once the season was established. Two such variables were the rainfall total for the 3-month period from January to March, and the length of the longest dry spell in this same period. In each of these cases the unit for analysis was the calculated value each year. So the step discussed in this section, of organising the data, is largely to transform the climatic data from the units as measured (i.e. daily) to the units for analysis (yearly). For a simple analysis, with most of the problems given here, the first stage is this transformation from daily to yearly values.

This next section assumes that the data have been obtained, and have been organised, so the units are those for the analysis. Often these provide as many values as there are years of data. The simplest analyses are just descriptive, and consist largely in producing the appropriate summary tables and graphs, as dictated by the objectives of the analysis. For example, for the analysis from Zambia, Fig. IV.7 shows the

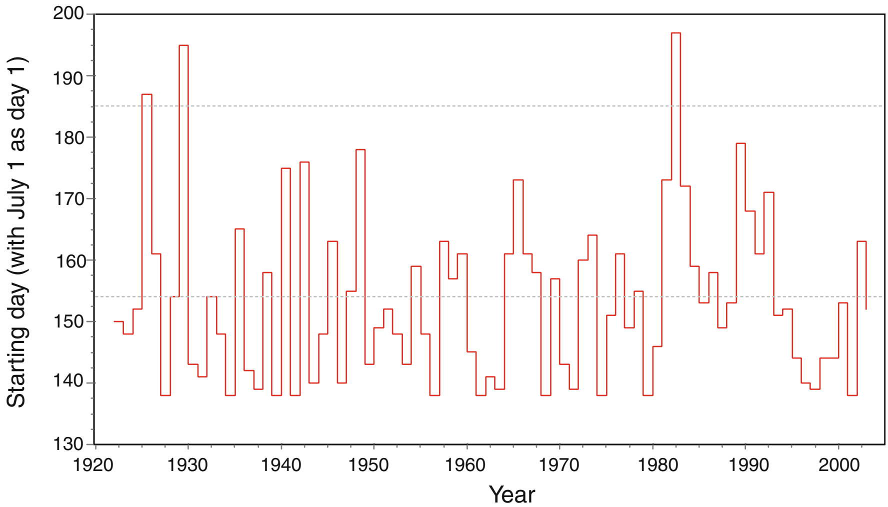


Fig. IV.7 Starting date of the rainy season, for Moorings (Zambia) 1922–2003 (First day with 20 mm in 3 days from 15 November and no dry spell exceeding 12 days in next 30 days) planting date for each year. This graph was also used as part of the visual evidence that there was no obvious change in the rainfall pattern that was sufficient to change the risks of a particular cropping strategy. Fig. IV.8 shows a set of graphs (called a trellis plot) that are produced together. The example shown is of the monthly rainfall totals, with a separate curve (a spline curve) fitted to the data for each month. This analysis used the statistics package called GenStat, for which a special climatic guide is available (Stern and Gallagher 2004).

There were changes, but not in a simple manner that indicated a consistent rise or drop in the rainfall totals during the record. A further analysis of the monthly data showed no evidence of a trend in the mean rain per rain day. The statistics package, Instat, includes a climatic guide that describes how these calculations are done (Stern et al. 2003). An equivalent set of graphs can also be given for the number of rain days per month, and this can present a clearer picture.

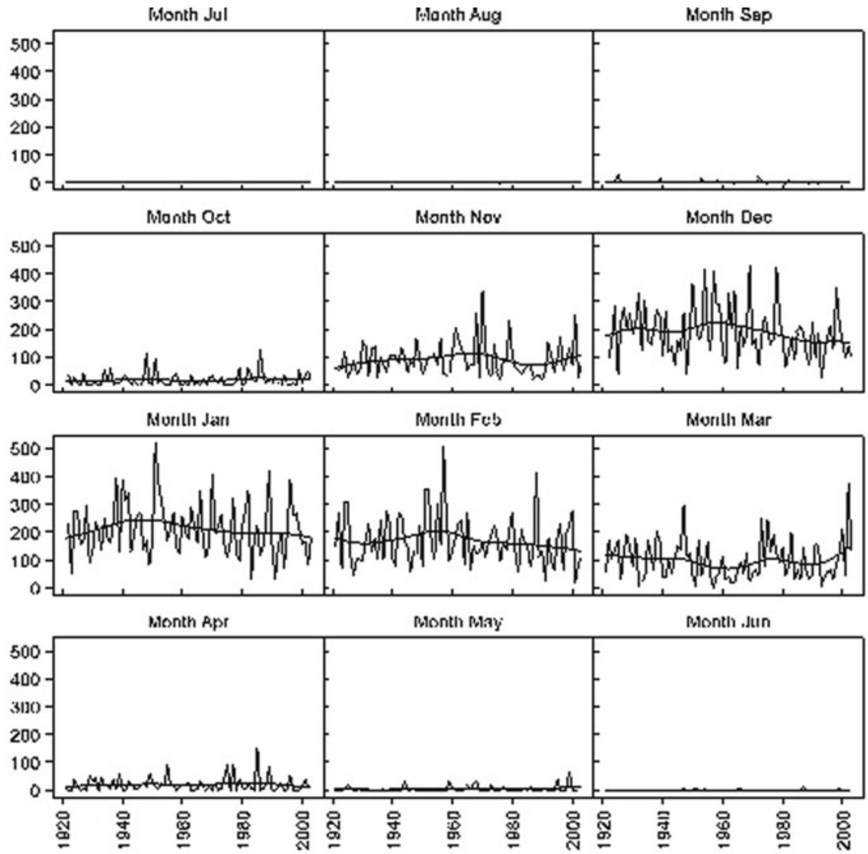


Fig. IV.8 Monthly rainfall totals for Moorings (Zambia) from 1921 to 2003 with fitted curves

Figure IV.9 follows from calculating the dry spell lengths for a series of overlapping periods and then calculating the proportion of years for which the dry spell lengths were longer than 10, 12 or 15 days within a 30-day period. This shows that planting rains on about 1st November (first vertical line) has about a 45% chance of being followed by a dry spell of more than 10 days in the next month. This risk drops to 1 year in four (25% of the years) by 15th November. The risk does not drop to zero (i.e. there is always a risk of a 10 day dry spell), but the fact that the lines in Fig. IV.9 are horizontal by late November shows that there is no benefit (in terms of reducing the risk) of waiting past this date.

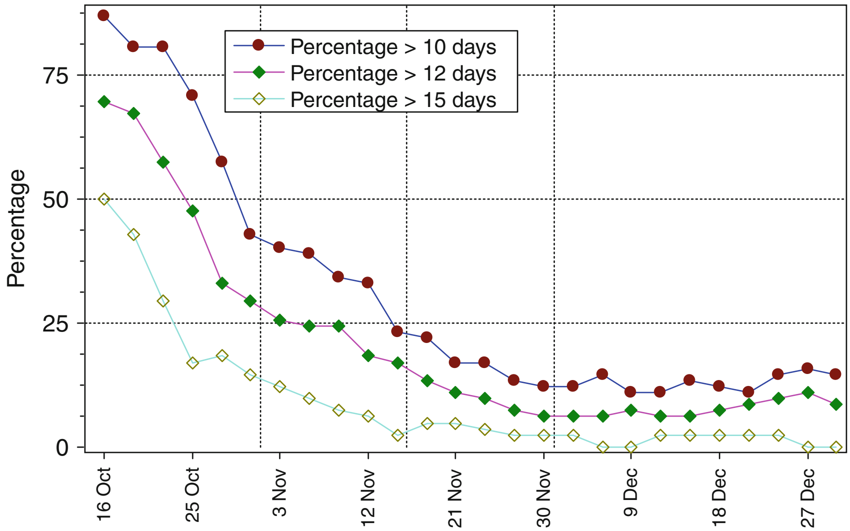


Fig. IV.9 Dry spells following planting, for Moorings (Zambia) (1922–2003)

During the season, flowering is a sensitive time for most crops. Discussion with the farmers indicated that, for maize, this sensitive period lasts for about 20 days. Figure IV.10 indicates that the risk for maize, of a long dry spell during flowering, is roughly constant, as long flowering starts by the beginning of February.

In Problem 1, on the planting date for cotton, the attempted solution, by the researcher, was to conduct an experiment, for 3 years. The analysis of the experimental data showed only that there is no "optimal" planting date – it varies from 1 year to another, and 3 years is a very short time to study this inter-annual variation. The analysis of the historical rainfall data, supplied by the NMHS, would have been a better approach.

Problem 2, on the farmers' perceptions of climate change, typifies many studies that try to determine user's views on climatic problems. This was a useful study, but might have been even more useful if an analysis of the historical data had been

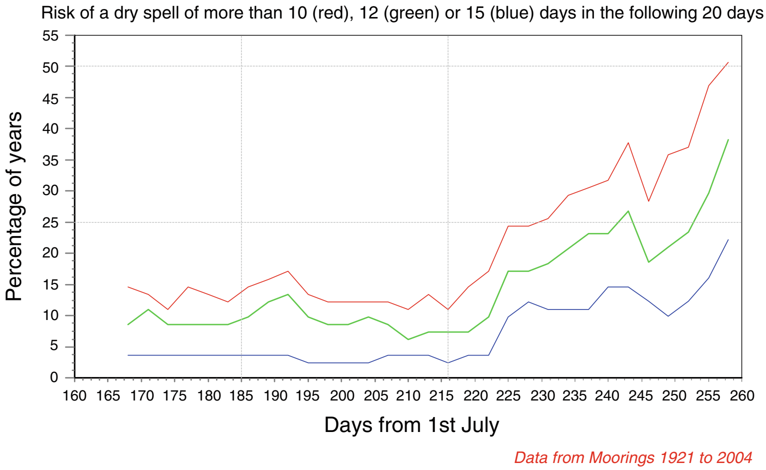


Fig. IV.10 Percentage of years at Moorings with a long dry spell during January–March

added, to assess the extent to which the evidence, of climate change, was consistent with the farmers' views.

This chapter has shown that simple analyses can provide answers to a few common problems. Much more can be done. The climatic records in many countries are available on quite a sparse grid, for varying numbers of years. In Australia Jeffrey et al. (2001) conducted a spatial and temporal analysis to provide complete estimated daily data on a grid with 4,600 points, in a form that is ready for inclusion in crop simulation models, such as DSSAT and ApSim (Table IV.1). This has simplified the use of these crop models considerably. It would be a formidable, but worthwhile task to emulate this work in other countries.

Table IV.1 Web sites for software and institutions mentioned in the text. CAST is general

Name	Application	Web site
ApSim	Crop simulation	www.apsim.info/apsim
CAST	Electronic statistics textbook	www.cast.massey.ac.nz
DSSAT	Crop simulation	www.icasa.net/dssat
GenStat	Statistical package	www.vsni.co.uk/genstat
Instat	Statistical package	www.reading.ac.uk/ssc
RSS	Institute	www.rss.org.uk
Wikipedia	On-line encyclopedia	www.wikipedia.org

References

Jeffrey JJ, Carter JO, Moodie KB, Beswick AR (2001) Using spatial interpolation to construct a comprehensive archive of Australian climate data. Environ Model Softw 16:309–330

Peck R, Casella G, Cobb G, Hoerl R, Nolan D, Starbuck R, Stern H (2006) Statistics: a guide to the unknown, 4th edn. Thomson/Brooks Cole, Belmont, 440pp

Stern RD, Gallagher J (2004) Analysing climatic data using Genstat for windows. Resources for statistical training and analysis, an index page of resources, under resources for statistical analysis and training. 206pp. www.reading.ac.uk/ssc

Stern RD, Knock J, Rijks D, Dale IC (2003) Instat climatic guide. Resources for statistical training and analysis, an index page of resources, under resources for statistical analysis and training. 398pp. www.reading.ac.uk/ssc

IV.11 Agrometeorological Statistics: More Introductory Issues and Cases

Olga C. Penalba

Cultivation of grain crops constitutes one of the most important agricultural activities in Argentina. They have been, and continue to be, subject to a wide scope of studies in the areas of economics, agronomics and agrometeorology. The agricultural activities involve a broad range of decision making in which various factors have significant influence. In this context, climate is a source of variability and risk, having in some situations a negative impact on agricultural activities. Therefore, it is necessary to assess the level of influence of temporal and spatial climate variability on crop yields. This evaluation is hampered by the complex quantification of the technological components intrinsically present in these activities.

Statistics is a science that analyzes series of data and tries to draw conclusions on the behavior of variables. Many processes in agriculture must be analyzed and explained in a probabilistic sense, because of their inherent randomness. Therefore, statistical methods are useful to organize, reduce and present observed data in a form that facilitates the data interpretation and data evaluation. Concerning data and the related investigations it is first necessary to recognize the different information going with the data: metadata and nature of the data. Subsequently it is needed to identify missing data and evaluate the data quality with specific statistical methodologies, depending on the variables (WMO 1986, 1990, 2003). Plants respond to many environmental factors such as temperature, rainfall, day length, carbon dioxide. So, there are various kinds of meteorological data in agricultural science and statistical methodologies are very useful to express different empirical relationships (see also Chaps. IV.7 and IV.9).

A frequency distribution is a representation in the form of tables of all the information that has been collected on a variable. These distributions are of particular interest in agricultural meteorology because they may give probabilities or risks of critical climate conditions, such as in amounts of rainfall or freezing temperatures

O.C. Penalba (✉)
Department of Sciences of the Atmosphere and Oceans, Faculty of Exact and Natural Sciences, University of Buenos Aires, Buenos Aires, Argentina
e-mail: penalba@at.fcen.uba.ar

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_111,

or numbers of dry days. Cumulative frequencies are particularly suitable and convenient for operational use in agrometeorology (Brooks and Carruthers 1953; Blalock 1979; Hoel 1984).

As an example, 5 years of total monthly rainfall at Posada station are presented in Table IV.2. Class intervals (lower and upper class boundaries), frequencies, relative frequencies and cumulative frequencies are given in Table IV.3. This frequency distribution can be represented graphically. Figure IV.11 shows the frequency histogram, where the heights of the columns in the graph are proportional to the class frequencies. Figure IV.12 represents the cumulative frequency distribution called "ogive". These tables and figures give useful statistical information for making decisions. For example, the probability that a monthly rainfall lies between 100 and 130 mm is 20% and the probability that a monthly rainfall is more than 250 mm is only 10%.

Humankind and the environment are far more vulnerable to extreme climate events than to medium climate variations. Rain is one of the climate variables with very great effects on land use, economic development, and practically all aspects of human activity. A comprehensive analysis of rainfall data is a crucial component in the management of water and agricultural production. Changes observed in monthly

Table IV.2 Records of 5 years of monthly rainfall for Posadas (27.25°S; 55.54°W) in Argentina, South America

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	152.4	103.0	217.8	62.6	52.6	115.2	36.6	18.3	118.3	116.2	212.0	194.8
1996	276.4	303.3	112.1	71.6	89.0	46.8	86.0	108.2	106.1	165.0	211.0	287.0
1997	73.9	181.6	132.2	85.0	111.7	43.0	123.9	99.2	133.6	145.5	295.0	319.0
1998	160.3	254.7	190.0	210.0	169.4	109.6	148.2	206.4	193.7	210.1	63.3	240.0
1999	124.1	185.0	137.0	215.0	133.0	120.5	150.1	19.1	227.1	155.0	111.0	243.0

Table IV.3 Frequency table of monthly rainfalls for Posadas (27.25°S; 55.54°W) in Argentina, South America, based on the data of Table 1

Class interval (mm)		Frequency	Relative frequency	Cumulative frequency
10.1	40	3	0.05	0.05
40.1	70	5	0.08	0.13
70.1	100	6	0.10	0.23
100.1	130	13	0.22	0.45
130.1	160	9	0.15	0.60
160.1	190	6	0.10	0.70
190.1	220	9	0.15	0.85
220.1	250	3	0.05	0.90
250.1	280	2	0.03	0.93
280.1	310	3	0.05	0.98
310.1	340	1	0.02	1.00
340.1	370	0	0.00	1.00
		60		

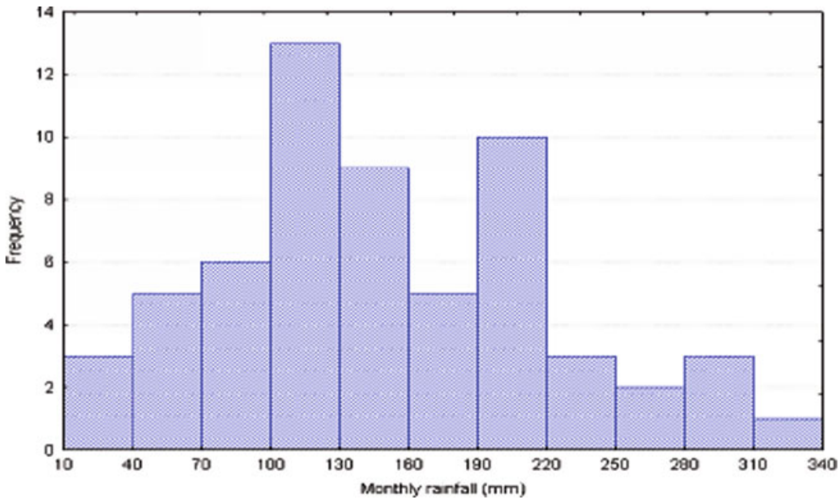


Fig. IV.11 Absolute frequency histogram of monthly rainfall for Posadas in Argentina, based on the data of Table IV.2

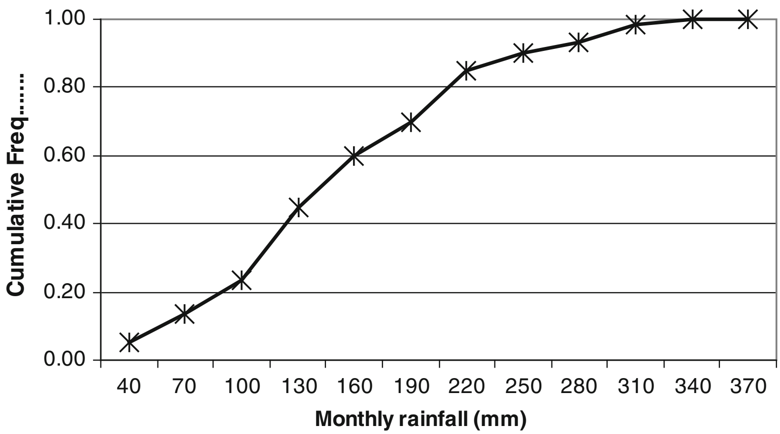


Fig. IV.12 Cumulative frequency histogram for Posadas in Argentina, based on the data of Table IV.2

rainfall may be due to changes in the number of rain days, in rainfall intensity, or both. Penalba and Robledo (2008) and Robledo and Penalba (2009) focus on both issues, especially extreme rainfall, and try to provide updated information on trends and interdecadal variability in southern South America.

Extreme events are infrequent meteorological phenomena and their severity depends on the natural environment affected. This means that the definition of an extreme event will largely depend on the activity and region affected (Das et al. 2003). In the particular case of extreme precipitation events, their definition depends, moreover, on the nature of the rainfall in the region under study.

Penalba and Robledo (2008) define a rain day as one on which the rainfall is greater than 0.1 mm and rainfall is considered extreme when the daily rainfall is greater than the 75th percentile (with a percentile each of the 100 equal groups into which a population of data can be divided). Now two indices were analyzed: the number of days with rainfall equal to or greater than the two thresholds mentioned above, calculating the percentage of events (hereafter: PE> 0.1; PE > 75th). To evaluate the trend, the authors applied the non-parametric Kendall-Tau test for the common period 1961–2000 (confidence level = 95%, critical $r = /0.22/$; Siegel 1985). This test is a rank-based procedure suitable for detecting non-linear trends in variables that do not have a Gaussian distribution, which is the case of the PE index.

Figure IV.13 shows the sign and significance of the annual PE > 0.1 and PE > 75th trends. Two large regions with spatial coherence in the significant trend for PE>0.1 are observed: one to the northeast and the other to the southwest of the region (Fig. IV.13, left). Although the trend decreases in some areas, only a few stations exhibit negative trends, towards the southeast. The spatial patterns seen in PE>0.1 trends do not persist with the same intensity in the extreme daily rainfall, PE>75th (Fig. IV.13, right).

Another interesting analysis which could be useful in agronomical management is to quantify the changes in these indices, calculating the difference in percentage of the PE>0.1 and PE>75th for two different periods (1961–1975 and 1980–1996). The annual PE>0.1 comparatively increased in practically the entire region by more than 10% for the period between 1980 and 1996 (Fig. IV.14, left), while annual PE>75th has some negative change nuclei, located at the upper and lower Uruguay basin (Fig. IV.14, right).

To determine which season is responsible for these changes, the percentages of seasonal change for each index were evaluated. The summer PE>0.1 spatial pattern (Fig. IV.15, DJF) resembles annual behavior with an increase of more than 10% in practically the entire region. The maximum changes, with over 25% change, occur in southern Brazil and the center west of the region under study. In winter (JJA), the

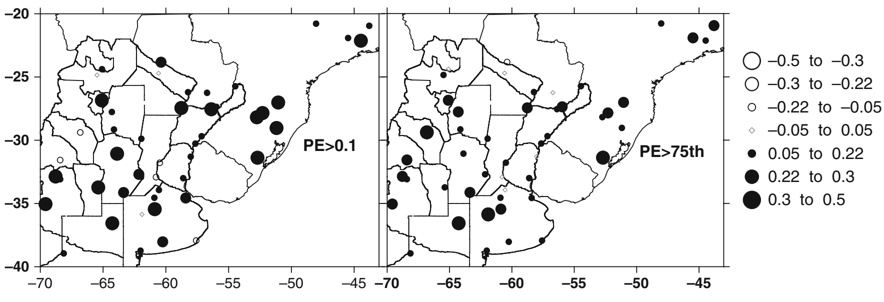


Fig. IV.13 Sign of the annual trend of the PE>0.1 (*left*) and PE>75th (*right*) as measured by Kendall Tau. An increase is showed by "•" and a decrease by "○". Values greater than (−0.22; +0.22) indicate significance $p < 0.05$

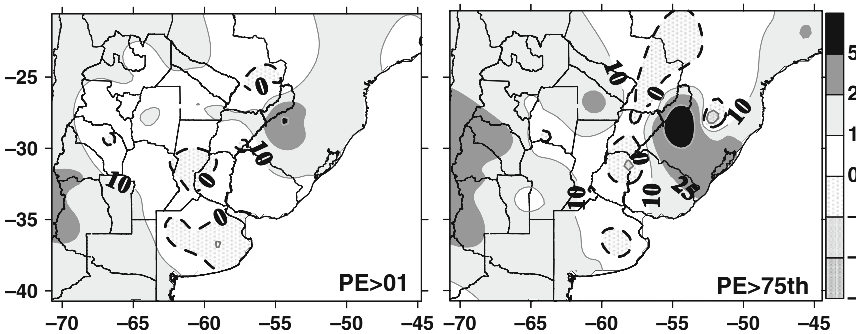


Fig. IV.14 Percentage of change for PE>0.1 (*left*) and PE>75th (*right*) between the periods 1961–1975 and 1980–1996

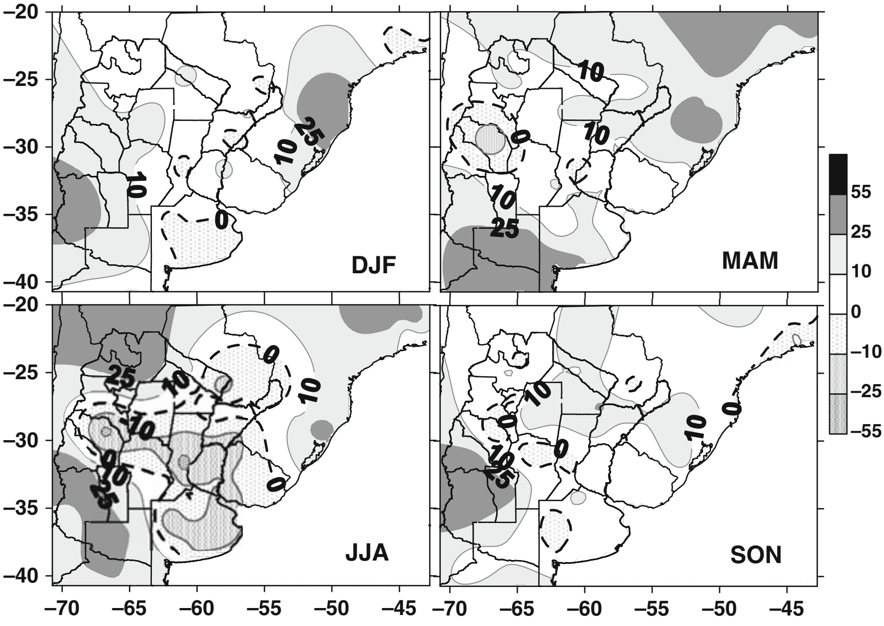


Fig. IV.15 Percentage of change for PE>0.1 between the periods 1961–1975 and 1980–1996 for summer (DJF), autumn (MAM), winter (JJA) and spring (SON)

"no or little change" center expands towards the east and northeast of the basin and has 10 and 25% fewer rain events from one period to the next.

The percentage changes of extreme events PE>75th (Fig. IV.16) are more marked than PE>0.1. Note how for this extreme condition the spatial change increases during the summer and winter months. In summer (Fig. IV.16, DJF), a negative change occurs of more than 10% in the middle of the Paraná and Uruguay River basins, while in winter (JJA) the PE>75th negative change area increases

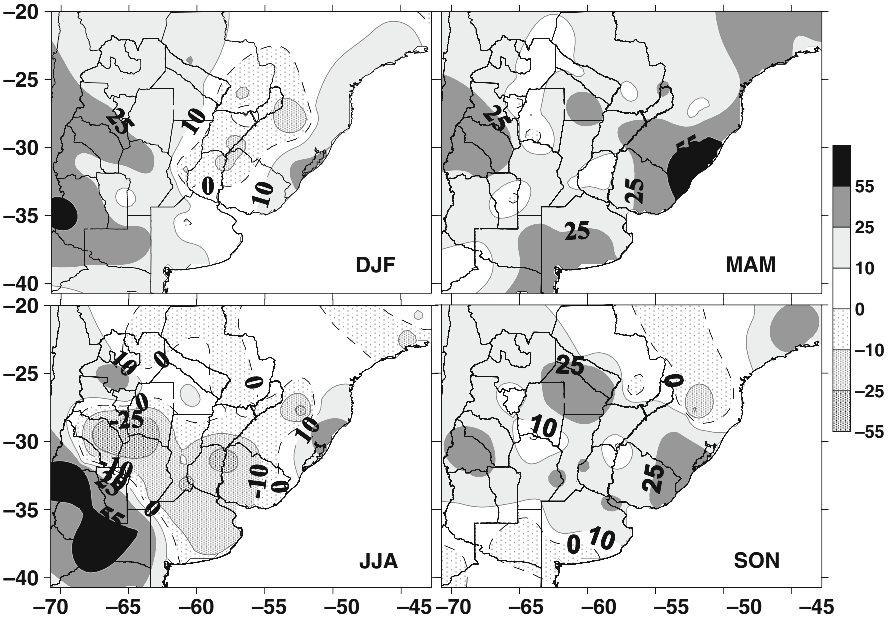


Fig. IV.16 Percentage of change for PE>75th between the periods 1961–1975 and 1980–1996 for summer (DJF), autumn (MAM), winter (JJA) and spring (SON)

with nuclei higher than 25% and moves southward. The knowledge of this temporal variability of extreme rainfall could provide useful information for decision making under conditions of a changing climate.

Research studies where the relationship between climatic variables and crops are quantified through statistical models at a regional scale are scarce in Argentina. More specifically, Minetti and Lamelas (1995) studied the response of soybean yields to climatic variability by means of a method of multiple regressions in San Miguel de Tucumán station (north-west of Argentina). They found that December rainfall and February mean thermal range are the variables that relate most to crop yields. They also observed that during the summer months (DJF) the need for soil water is greater, whereas in the 4-month term of JFMA, soybean needs more air humidity.

The main goal of Penalba et al. (2007) was to assess the impacts of climate variability on agriculture in the Pampas region, agricultural region par excellence of Argentina. The authors analyzed two data sets of the period 1973–2000: (a) daily rainfall and maximum and minimum temperatures; (b) soybean yields (estimated as the ratio of total production to area harvested). First they analyzed the soybean yield behavior via the first moments of their distribution. The mean pattern of soybean yields shows a core higher than 2,100 kg ha^{-1} north of Buenos Aires, south of Santa Fe and southeast of Cordoba (Fig. IV.17(a)).

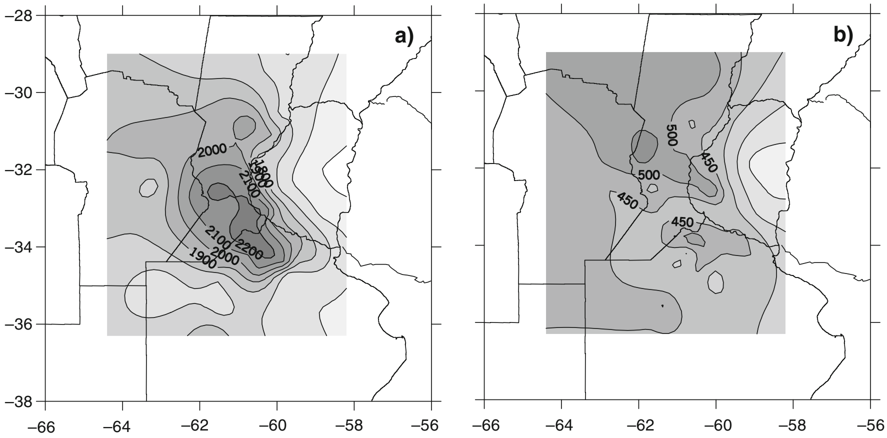


Fig. IV.17 (**a**) Soybean mean yield field [kg ha^{-1}]; (**b**) Yield standard deviations

The standard deviations of these series present the largest values to the central northwest of the region, decreasing towards the east (Fig. IV.17(b)). This maximum variability (high standard deviation values) appears to be due to the effect of the significant positive linear yield trend over time. On filtering the trend, the standard deviation field of the series does not show such high variabilities. Agricultural yield data typically have an upward low-frequency trend because of technological improvements in crop genetics and management techniques (e.g. Hall et al. 1992).

The authors also analyzed the spatial structure of the soybean yield field, calculating simple correlations among the series of yield anomalies. Figure IV.18 shows the correlation fields of five departments (located at the north, south, east, west and centre of the study region). The highest spatial coherence corresponds to the department located at the central zone. This significant correlation field extends across almost the whole region considered. Correlation patterns found in the western and eastern zones of this region are more localized and restricted to each respective zone. The lowest spatial coherence is the one presented by the correlation fields located at the north and south border zones. These results indicate low spatial coherence of yields, except for the pockets located in the soybean core region. Therefore, variable yield is representative in sub-regions. This suggests that regional estimations of soybean yield have to be analyzed carefully on account of the low spatial coherence (for example, a real average of the yield would not be representative for the whole region).

Soil and climatic conditions in the Pampas are suitable for cultivation of soybean. However, sometimes rainfall and temperature extremes occur during the critical period of soybean development. Initially, in order to evaluate the degree of association between climate variability and soybean yield, the simple correlation between each of the monthly climatic anomalies and yield anomalies was calculated by Penalba et al. (2007). In general, no marked regional behavior of the relationship

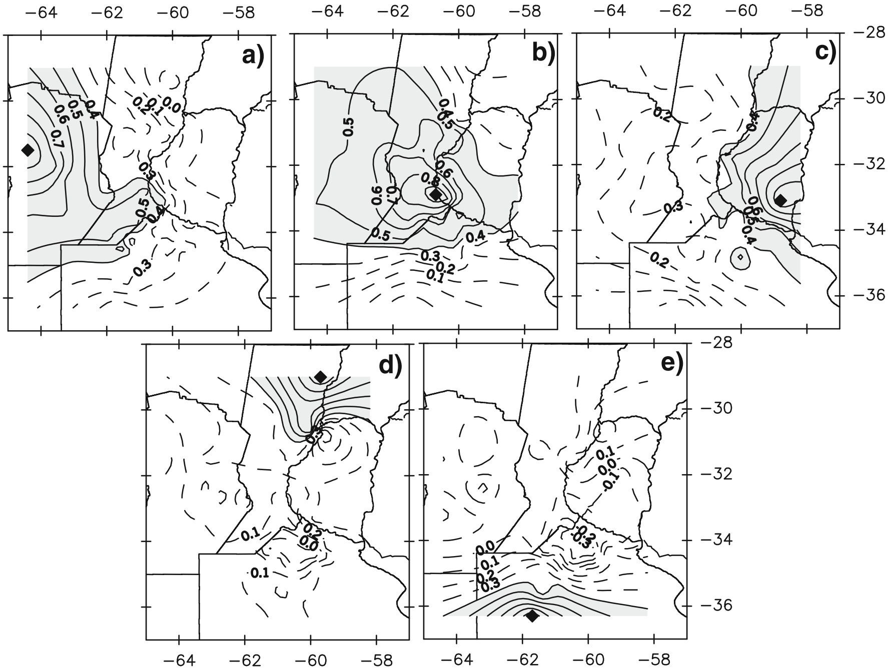


Fig. IV.18 Correlation fields of soybean yield in west (**a**), center (**b**), east (**c**), north (**d**) and south (**e**) departments (*diamonds*). *Shaded area*: correlation coefficients significant at the 95% confidence level

between the variables is observed, in spite of a defined pattern in the indicators of the correlation, whether or not it is significant (Table IV.4). Yield presents a positive correlation with rainfall from October to February inclusive. Meanwhile, from March onwards this correlation becomes negative.

This shows that higher rainfall positive anomalies during the maturity to harvest period have a negative impact on the final yield of the crop, as was already shown to exist by Pascale et al. (1983). The relation between yield and monthly mean maximum temperature is observed to be negative from December to April, while the correlation between the yield and the monthly mean minimum temperature stands out mainly positively in the first months (ON). The association between yield and monthly mean thermal amplitude is negative and statistically significant in the

Table IV.4 Correlations between the anomalies of the climatic variables and yield for Junín station (**) 95% and (*) 90% significance

Junín	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Rainfall	0.25	0.51**	0.22	0.22	0.13	−0.19	−0.34**	−0.27
Max T	0.30	0.15	−0.28	−0.19	−0.13	−0.41**	−0.36**	−0.01
Min T	0.59**	0.51**	0.20	−0.08	0.28	0.04	−0.08	−0.17
ΔT	−0.23	−0.24	−0.40**	−0.12	−0.34**	−0.49**	−0.20	0.18

summer months (DFM). Such statistically significant results confirm the sensitivity of the soybean crop to different extremes of climatic conditions (high and low temperatures, low humidity) in different crop cycle stages (Da Mota 1978).

Finally, the authors analyzed the joint effect of climatic variables on final yields of the crop, using stepwise multiple regression. The predictor variables proposed in each regression were selected according to the different months of the crop cycle stages, the variables mentioned in works by other authors, and the significant correlations between yield and the climatic variables concerned.

The resulting regression model in Junín station is

$$\Delta R = 0.37 + 167.7\Delta T\,\mathrm{min}_{\mathrm{Oct}} - 125.6\Delta T\,\mathrm{max}_{\mathrm{Mar}} + 1.36\Delta \mathrm{PP}_{\mathrm{Mar}} + 1.78\Delta \mathrm{PP}_{\mathrm{Nov}} \\ -72.4\Delta T\,\mathrm{max}_{\mathrm{Apr}}$$

where ΔR are simulated anomalies of detrended soybean yield in Junín station; $\Delta T\,\mathrm{max}_{\mathrm{Mar}}$ are anomalies of maximum air temperature in March; $\Delta T\,\mathrm{min}_{\mathrm{Oct}}$, are anomalies of minimum air temperature in October; and $\Delta \mathrm{PP}_{\mathrm{Mar}}$, $\Delta \mathrm{PP}_{\mathrm{Nov}}$ are anomalies of rainfall in March and November. The variabilities of the observed and estimated yield anomalies resulting from this model are in phase with a r^2 of 0.84 (Fig. IV.19).

The November positive rainfall anomalies favor the final yield since these are associated with soil water availability (Hurtado et al. 2001). November rainfall in this location is significantly correlated to the same variable in October. The water availability in the soil is reflected in the same way by the minimum temperature of October being significantly associated with the precipitation and thermal amplitude of the same month (pre-sowing). Negative anomalies in rainfall and positive ones in maximum temperature in March (warm and dry conditions) produce a decrease in the yield.

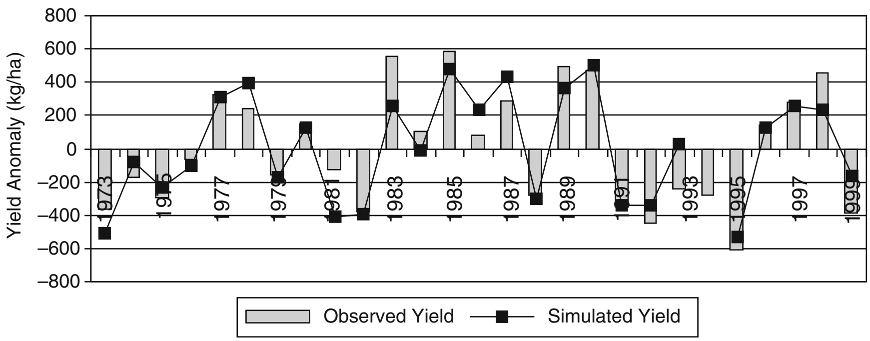


Fig. IV.19 Observed and simulated yield anomalies of soybean during the period 1973–2000 for Junín

All stations analyzed by Penalba et al. (2007) show that in general yield has a strong association with monthly extreme temperature at important phenological moments of the crop, which in turn show a significant correlation with the monthly rainfall. Moreover, the predictor variables for each regression model appear to depend on the location. The same results were observed in the other analyzed locations not presented in this work. The case studies presented here illustrate the value of statistical analyses in preparing the determination of complicated cause and effect relationships between climate and yields.

References

Blalock HM (1979) Social statistics. McGraw-Hill, New York, etc, 625pp

Brooks CEP, Carruthers N (1953) Handbook of statistical methods in meteorology, Her Majesty's Stationery Office, London, 412pp

Da Mota FS (1978). Soya bean and weather. WMO Technical Note 160, Geneva, 64pp

Das HP, Adamenko TI, Anaman KA, Gommes RG, Johnson (2003) Agrometeorology related to extreme events. WMO Technical Note 201, Geneva, 137pp

Hall AJ, Rebella CM, Ghersa CM, Culto JP (1992) In: Pearson CJ (ed) Field-crop systems of the Pampas. Ecosystems of the World: field-crop ecosystems. Elsevier, Amsterdam, pp 413–449

Hoel PG (1984) Introduction to mathematical statistics. Wiley, Singapore, 435pp

Hurtado R, Fernández Long ME, Spescha L, Murphy G (2001) Distribución espacial de los rendimientos extremos de soja en la Región Pampeana y condiciones climáticas que los acompañan. [Spatial distribution of the extreme yields of soybean in the Pampan Region and related climatic conditions.] Proceedings of the XIIth Brazilian Congress of Agrometeorology and IIIrd Latino-American Meeting of Agrometeorology, Fortaleza, 3–6 July, pp 25–31

Minetti JL, Lamelas CM (1995) Respuesta regional de la soja en Tucumán a la variabilidad climática. [Regional response of soybean in Tucumán to the climatic variability.] Rev Industr Agríc Tucumán 72:63–68

Pascale AJ, Miaczynski CR, Rodríguez RO, Trigo ER (1983) Aptitud ecológica de la región oriental argentina para el cultivo de la soja. [Ecological suitability of the eastern region of Argentina for soybean]. Preprints VIIIth National Technical Meeting on Soybean, Tucumán, Argentina, B1–B19

Penalba O, Robledo F (2008) Spatial and temporal variability of the frequency of extreme daily rainfall regime in the La Plata Basin during the 20th century. Clim Change, Special Issue, 98:531–550

Penalba OC, Bettolli ML, Vargas WM (2007) The impact of climate variability on soybean yields in Argentina. Multivariate regression. Meteorol Appl 14:3–14

Robledo F, Penalba O (2009) Temporal and spatial variability of daily intensity of rainfall and its relation with surface atmospheric circulation in South-eastern South America, 9th International Conference on Southern Hemisphere Meteorology and Oceanography, Melbourne, Australia, 9–13 February, http://www.bom.gov.au/events/9icshmo/manuscripts/PTH_D14_Robledo.pdf

Siegel S (1985) Estadística no paramétrica aplicada a las ciencias de la conducta. [Nonparametric statistics for the behavioral sciences.] Editorial Trillas, http://www.trillas.com.mx/corpoingles.html, 344 pp

WMO (1986) Guidelines on the quality control of surface climatological data. Prepared by Abbott PF. WMO/TD 111, Geneva, 243pp

WMO (1990) On the statistical analysis of series of observations. Technical Note 143, Geneva, 192pp

WMO (2003) Fourth seminar for homogenization and quality control in climatological databases. World Climate Data and Monitoring Programme 56, 6–10 October, Budapest, Hungary, WMO/TD 1236, Geneva, 243pp

IV.12 Climate Prediction and Weather Forecasting

Nathaniel Logar

Agricultural science is often directed towards an identified application or need. However, a goal of application does not ensure a successful science program. For example, since 1989, the US spent approximately $2 billion dollars per year on climate change research that purportedly aimed to support decisions. However, there is little evidence that it produced a commensurate amount of useable information (Pielke Jr. and Sarewitz 2003), due to problems of legislative ambiguity, models of scientific thought and a tenuous relationship between the realities of modeling and needed information (see also Chaps. IV.3, IV.9 and IV.17). Unlike some other fields, such as theoretical physics or astronomy, agricultural and meteorological research have not historically been disconnected from concerns of application and use. However, creating linkages between research programs intended for decision support and benefit to societal actors, including agricultural producers and decision makers, is fraught with complexities of context, ideology, and institutional design.

The challenges of making predictions that are relevant to agricultural decision makers is to give them timely, salient information that links the knowledge accrual processes of the scientific supply side to the demand of decision makers. Designing research endeavors that can accomplish this is difficult because:

- Predictions, even when accurate, often fall in the wrong timeframe, or lack needed specificity.
- The uncertainties inherent in prediction may not be made apparent to those using the predictions.
- Science policy makers often misconstrue the context of application.

Evidence of the first two points is available in the case of climate models. In his article, “Overheated Claims”, Roger Pielke Jr. makes the point that people who support action to mitigate climate change, including climate scientists, often rhetorically inflate the ability of climate models to predict the future. In the case

N. Logar (✉)
Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, Cambridge, MA, USA
e-mail: nat.logar@gmail.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_112,

for climate change model predictions, there has been a rash of scientists claiming that recent weather extremes have been consistent with model claims, despite large discrepancies between the spatial or temporal timescales of the weather events and the predictive capability of the models (Pielke Jr. 2008). Almost any foreseeable short-term weather event can fit into the longer term, lower resolution predictions of climate modelers.

However, if researchers tell decision makers that a specific weather event conforms to the prediction of the climate modelers, an average decision maker may come away with the impression that climate models are capable of predicting short term weather, and that they can continue to rely on their weather predictions in the future. Furthermore, decision makers may believe that the so-called conformity of the climate model to short term weather validates the longer term predictions of the model, and thus is a basis on which climate policy decisions can be accurately made. Neither of these things are necessarily true. Thus, the claims of climate modelers can bring decision makers to a place where they are either incorrectly placing faith in the models, or where they make a decision, the model is wrong, and the decision maker blames the modeler.

A large part of these possible complications is an artifact of inaccurate statements being made by modelers, but another contributing factor stems from policy makers funding predictive models, because they expect them to answer important policy questions, but not necessarily funding the right modeling to do so. Most climate models will not address anyone's concerns in regards to short term weather, but why is this important if meteorological organizations already exist to study such patterns? Most meteorological models, where predictions typically span a number of days, are not on the only prediction needed. Agricultural decision makers often require information on timescales related to climate variability ranging from seasonal to decadal, such as drought forecasts and ENSO predictions.

For example, one finding of a study on forecast application in northeast Brazil found that seasonal climate forecasting "has the potential to offer a dramatic opportunity for state and local level bureaucracies to embark on a path of proactive drought planning" (Lemos et al. 2002). However, much of the money spent on predicting climate goes to global climate models, which are not capable of the resolution needed for prediction regarding climate variability. Additionally, the pursuit of a seasonal forecast model is in no means a guarantor of success. Lemos et al. (2002) found problems with seasonal forecasts similar to those Pielke mentions. Both political overselling of the forecasts' ability, and a gap between forecast skill and information needed to make a decision, attenuated the effectiveness. Box IV.13 reviews the way Stigter (2004) read the lessons from Lemos et al. (2002).

Box IV.13

Stigter (2004) dealt with the lessons from Lemos et al. (2002) as follows. In this Brazilian example, drought forecasts have been directed towards small-scale rainfed agriculturists as well as state and local level policy makers in the areas of agriculture, water management, and emergency drought relief. Ceará state has the largest proportion of its territory characterized as semi-arid and is highly vulnerable to drought, which shaped culture, environment, politics and society. It is ravaged by poverty and over a century local and national governments have attempted to respond to the challenge of drought with limited success. It was also the first northeastern state to acquire technical expertise on regional climate science and to attribute climate forecasting to the mandate of a public institution.

A first lesson drawn by the authors was that an emergency technology "was appropriated and pressed into service of a policy making apparatus designed to reduce the impacts of severe droughts". Policy makers started to exaggerate the potential usefulness of the science product, "therefore creating a situation of cultural dissonance between science and local knowledge and belief systems that quickly eroded the value of the information". A second lesson drawn was the failure that the government wanted to use the forecast to manage agriculture for the farmers, particularly by interfering in the availability of seeding material, instead of leaving decisions on planning etc. to the farmers. This gave unnecessary resentment and has been abandoned. The third lesson that the authors of this case study want to draw is "that the forecast is limited by the socio-economic conditions of the beneficiary population". Most farmers in Cereá are so vulnerable to climatic variability that they are unable to respond to raw climatic predictions, irrespective of the quality and the precision of the forecast.

The authors of the case study indicate that the researchers have now changed their focus from items around the start of the rainy season to studies of dry spells and pre-season weather/climate patterns (response farming, easing preparations). The authors conclude overall that in the Cereá case study, the limits of the use of climate information in policy making derive in part from the levels of skill and direct usefulness of the science products themselves and in part from the necessity for a policy making apparatus to learn how to apply it usefully. In comparison to farming communities, the authors' assessments for the future give a more positive outlook for success with the use of forecasting products for "intermediate" organizations: (i) policy making government extension programs; (ii) drought relief organizations; (iii) water resource management bodies; (iv) infrastructure planning and infrastructure maintenance institutions.

The Brazilian case indeed shows that as a consequence of insufficient knowledge of the conditions that actually shape the livelihood of farmers, we have too often insufficiently taken into account local adaptive strategies; not made the right choices in the use of contemporary science; indeed not understood the overwhelming effect of inappropriate policy environments

(Stigter 2004). Fortunately, more recently a new sense of objective, rational professionalism has supplanted the old patronage and clientilism system, and the delivery of government services to states like Cereá has been held to new accountable standards (Finan 2003).

A compounding issue involves fomenting reconciliation between the stated goals of a research program and what it can plausibly deliver. If the US Climate Change Science Program (CCSP) promises decision support, but largely fails in that, it suffers in terms of the salience of its product and the perceived legitimacy of the organization, both of which are important characteristics of science that successfully link scientific knowledge to actionable outcomes (Cash et al. 2002).

In many countries, such as the United States, climate models are advocated for, funded, and developed in institutions that are explicitly focused on providing decision aids to policymakers. Both the interagency CCSP and its constituent federal institutions promise useful climate information. For example, the US Agricultural Research Service (ARS) promises to "develop and provide adaptation, mitigation, and management strategies to the individual farm, ranch, and rural community, and to natural resource decision-makers to allow them to derive optimal benefit from the positive aspects of global change and deal effectively with the detrimental effects" (ARS 2000).

Above, it was mentioned that science decision makers often fail to account for the context of application, promising relevant knowledge but failing to address how relevant information will reach decision makers. After study of the climate research programs within the ARS, it is evident, as one ARS staff member said, that "Global climate change is a Washington, DC policy maker issue. It's not a farm issue" (Follett, personal communication 2005). The ARS mandate charges it with providing useful information to farmers. At the same time, it receives a certain amount of money that it must devote to climate change, despite this characterization as a non-issue, and is thus left with a challenge in deciding what to prioritize.

Part of the reason for this problem, and for many problems in the prioritization and execution of public science, is that the views of the people who are supposed to be benefiting from the science are not fully taken into account. Much of the policy that drives predictive science in the US is the result of political decisions made at the national level, like Presidential directives (Office of the Press Secretary 2002). In the US, long term climate prediction is not "on the radar" (Follett, personal communication 2005; Hatfield, personal communication 2005) for many farmers, since it is not tied to production issues. But if it is going forward anyway, science decision makers are obviously not fully or accurately accounting for the context in which the science will find use. Lemos et al. (2002), working on seasonal forecast models, also found that the political and scientific process failed "to take into account end users' needs and decision making behavior". See also Box IV.13.

While long-term planning and anticipatory research is important in addition to short-term productivity, farmers must see plausible productivity benefits from science programs that are aimed at them. Often, they do not. The Minnesota Corn Growers are a regional farmers' association that interacts frequently with scientists in the ARS. They participate to the extent that they are willing to send members to ARS strategic planning meetings, such as those for research in Soil Resource Management or Water Resource Management. However, they have also interacted with members of the ARS global change research program, and have declined to send members to meetings in the past, because they do not consider climate change as a productivity issue, and thus cannot justify the cost (Baker, personal communication 2005). Thus, you see an organization that is focusing predictive resources on a topic area, but an invested stakeholder group that sees no benefit coming from the area, to the point where they refuse to take part, despite being given the opportunity to shape the path research might take.

In the case of the ARS, much of the money that is distributed to agricultural climate research is devoted to understanding the responses of soil carbon storage to different regimes, which stems from a statement made by President Bush in 2002 (Office of the Press Secretary 2002). While increasing the organic material in soils can benefit farmers regardless of climate change, the precise quantification of how much carbon a soil can hold is an issue specific to climate change. Farmers may only see benefit from this aspect of the research if the political field changes to alter policy so that they are being paid for sequestering carbon.

Thus, while work that helps farmers increase soil organic matter, and thus mitigate climate change, is a "win-win" situation, in that benefits accrue despite any action on climate (Kimble et al. 2003), precise carbon accounting might only be successful with further political action. At the same time, there are other decision support tools, perhaps on regional or seasonal climate forecasting, that could enable improved outcomes now. The political situation has defined the current arena so that research is being done that will not maximally benefit farmers until an uncertain future political choice changes farm legislation to pay farmers for carbon sequestration (Logar and Conant 2007).

Designing useable forecast systems, given the complications of context, politics, and forecast skill, is difficult. Some of these factors are unalterable at the level of research project prioritization. However, research planners can work in some ways to improve the fit between the supply of science and the information needs of the users, simply through more interaction and consideration of user needs, especially at the levels where new modeling ventures are being instituted and deployed.

Many authors have discussed the relationships between improved agricultural outcomes and the projects of research. Several authors have found better results from scientists collaborating with users (Gadgil et al. 2002; Siepen and Westrup 2002) and from competent management of the boundary between agricultural science and the managers it serves (Cash 2001). However, collaborative processes do not guarantee success (Korfmacher and Koontz 2003). Thus, investigating the whole policy context, including the expectations set by policy makers and the potential for the prediction to have sufficient skill, along with user needs, is important to gain a comprehensive view of how supply of science might match demand.

References

ARS (2000) Global change national program action plan. Agricultural Research Service, Beltsville, 23pp

Cash DW (2001) In order to aid in diffusing useful and practical information: agricultural extension and boundary organizations. Sci Technol Human Values 26:431–453

Cash DW, Clark W, Alcock F, Dickson N, Eckley N, Jager J (2002) Salience, credibility, legitimacy and boundaries: linking research, assessment and decision making. John F. Kennedy School of Government, Harvard University, Cambridge, 23pp

Finan TJ (2003) Climate science and the policy of drought mitigation in Cereá, northern Brazil. In: Strauss S, Orlove B (eds) Weather, climate, culture. Berg, Oxford, pp 203–216

Gadgil S, Seshagiri Rao PR, Narahari Rao K (2002) Use of climate information for farm-level decision making: rainfed groundnut in southern India. Agric Syst 74:431–457

Kimble JM, Everett LR, Follett R, Lal R (2003) Carbon sequestration and the integration of science, farming and policy. In: Kimble JM, Lal R, Follett R (eds) Agricultural practices and policies for carbon sequestration. Lewis Publishers, Boca Raton, pp 3–11

Korfmacher KS, Koontz TM (2003) Collaboration, information, and preservation: the role of expertise in farmland preservation task forces. Policy Sci 36:213–236

Lemos MC, Finan TJ, Fox RW, Nelson DR, Tucker J (2002) The use of seasonal climate forecasting in policymaking: lessons from Northeast Brazil. Clim Change 55:479–507

Logar N, Conant R (2007) Reconciling the supply and demand for carbon cycle science in the US agricultural sector. Environ Sci Policy 10:75–84

Office of the Press Secretary (2002) President announces clear skies and global change initiatives. Statement of George W. Bush at the National Oceanic and Atmospheric Administration, Silver Spring, MD, 14 February. http://www.whitehouse.gov/news/releases/2002/02/20020214-5.html

Pielke Jr RA (2008) Overheated claims. Financial Post. June 17. http://network.nationalpost.com/np/blogs/fpcomment/archive/2008/06/17/overheated-claims.aspx

Pielke Jr RA, Sarewitz D (2003) Wanted: Scientific leadership on climate change. Issues Sci Technol, Winter Issue:27–30

Siepen GL, Westrup J (2002) Communicating vegetation management science to land managers and other stakeholders. Rangel J 24:170–181

Stigter CJ (2004) The establishment of needs for climate forecasts and other agromet information for agriculture by local, national and regional decision-makers and users communities. In: Applications of climate forecasts for agriculture. Proceedings of the RA I (Africa) Expert Group Meeting in Banjul, the Gambia (December 2002). AGM-7/WCAC-1, WMO/TD-No. 1223, WMO, Geneva, pp 73–86

IV.13 Examples of Agrometeorological Decision Support Developed and Used in South America

Orivaldo Brunini, Mário José Pedro, Jr., Dalziza De Oliveira, Marcelo Bento Paes De Camargo, Glauco De Souza Rolim, and Paulo Henrique Caramori

South America has contrasting climatic regimes, with conditions from the equatorial hot and humid to extremely dry or cold, to even tropical or subtropical conditions. This vast climatic range is shown in Figs. IV.20, IV.21, IV.22 and IV.23, displaying average yearly temperature regimes, rainfall distribution, annual water deficiency and an annual soil moisture index, the last two established by a water balance method according to Thornthwaite and Mather (1955), and using software developed by Brunini and Caputi (2001).

These great climatic differences favor the agricultural development and exploration of numerous vegetative species, such as in the Amazon rainforest, subsystem cultures, great commodities as soybeans, corn, coffee, and sugarcane, and regional adaptations ranging from temperate climate to tropical species. Therefore, agrometeorological decision support for agrometeorological services and information under development or to be implemented should address the different regional threats (Caramori et al. 2003).

On the other hand, although all countries have reasonably good NMHSs, some agrometeorology or agrometeorological decision support products do not receive their due recognition. Agrometeorological decision support products available in South America are quite differentiated when referring to this type of information and regarding the target audience.

In Venezuela, agrometeorology coordination at national level is made by the *Serviço de Meteorologia de la Aviación* (www.meteorologia.mil.ve). Notice that most decision support products are aimed at weather forecasts and support to hydrology. The Venezuelan Society of Agrometeorology is striving to provide research information to farmers.

In Peru, the NMHS (SENAMHI) develops excellent work, providing agrometeorological information and decision support products at a national level. Through agrometeorological monitoring (www.senamhi.gob.pe), a detailed study was

O. Brunini (✉)
IAC, Campinas, São Paulo, Brazil
e-mail: brunini@iac.sp.gov.br

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_113,

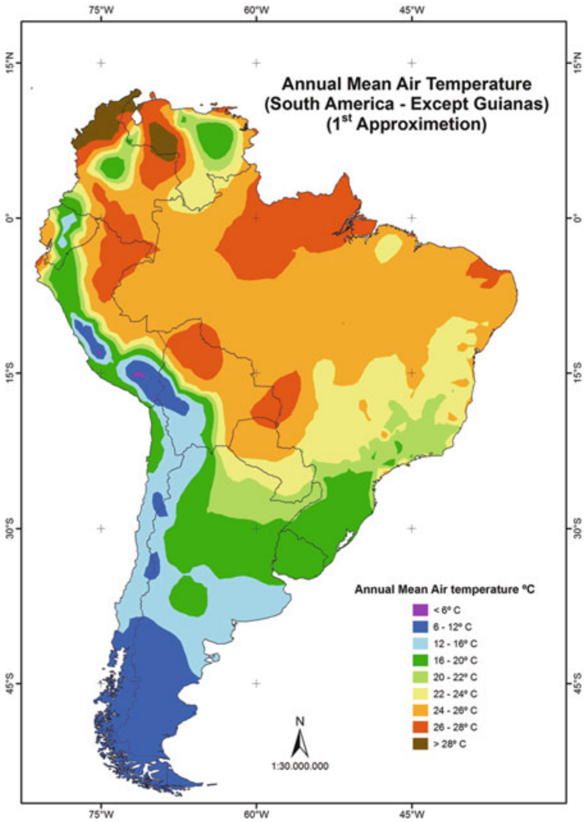


Fig. IV.20 Annual mean air temperature for South America, except for the Guianas (1st approximation)

conducted on the agrometeorology of different crops in the main river basins and valleys, thus contributing to the development of more sustainable agriculture. The studies range from phenological information, for those locations that have a national phenology network, to monitoring and the communication of agrometeorological information. It estimates crop yields as well as monitors pests and diseases. The current climatic situation and future weather forecasts and their impacts on crops are covered and evaluated in detail.

Chile is also known for their use and forecast of meteorological information for decision support in agriculture (www.meteochile.cl). Agrometeorological information is either centralized in the Chilean Meteorological Department or in the Regional Centers of Agrometeorological Information (CRIA), where the farmer may access operational information, agricultural forecasts, and agrometeorological updates in real time. This information covers from weekly analyses of agrometeorological perspectives to trends and bulletins and effects on different crops and agricultural practices. Issues regarding agrometeorological forecasts for different regions and

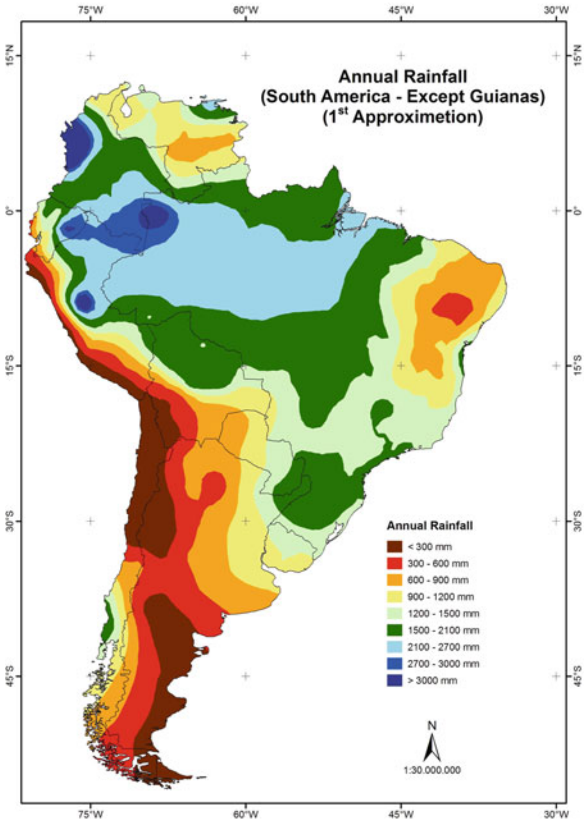


Fig. IV.21 Annual rainfall for South America, except for the Guianas (1st approximation)

weekly updates of cold periods are also covered. Agroclimatic risk assessment is made according to the probability of the occurrence of adverse events. The country also actively participates in the "Climatic Information Applied to Coping with Agricultural Risk in Andean Countries" (CYFEN) project. General information is given about the behavior of meteorological elements and forecasts are made on a regular basis to support decisions.

Ecuador, through the National Institute of Meteorology and Hydrology (www.inamhi.gov.ec), develops regular bulletins at 10-day and monthly intervals concerning the impacts of agrometeorological parameters on crops. Ecuador is the headquarters for the CYFEN project. The country also has an advisory and alerting service regarding meteorological adversities and climatic risks.

In Argentina, the National Institute of Agricultural Technology, INTA (www.inta.gov.br) developed studies and provides specific decision support information via internet on crop development, amounts of water in the soil and agrometeorological characteristics of Argentina's climatic zones. Information regarding crop develop-

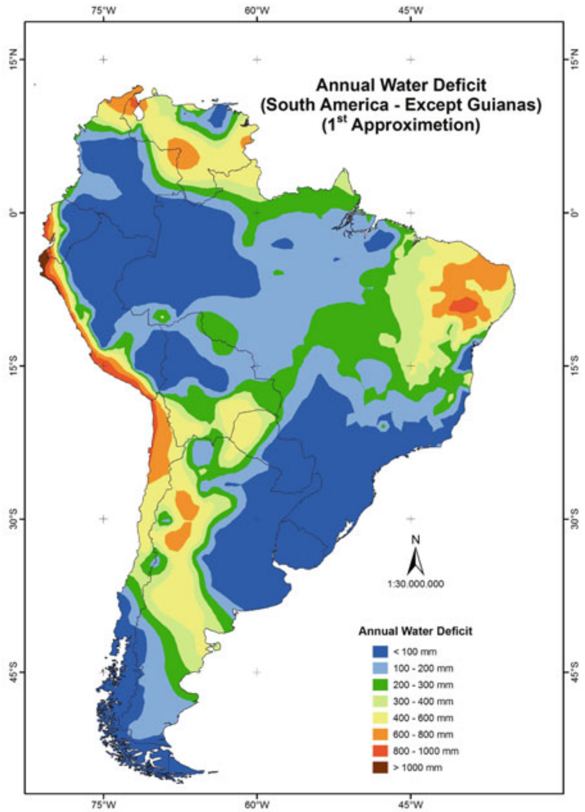


Fig. IV.22 Annual mean water deficits for South America, except for the Guianas (1st approximation)

ment, drought forecasts and the effect of climate variability on crop production can also be found. Besides these specific agrometeorological decision support products, information about statistical meteorological data, rain and hail estimates, accumulated precipitation, and a forecast and prognosis of drought are analyzed and periodically made available to users to support decisions.

The National Institute of Agricultural Investigation of Uruguay (INIA), through its Agroclimate Information System Unit (www.inia.org.uy/gras) makes various agrometeorological products available to farmers, such as quarterly climatic views, water balance, frost predictions, and daily rainfall registration. Two alert systems, for stem disease in sunflowers and *fusarium* for wheat spikelets, can be highlighted as currently in use. They make decision support information available about the possibility of these diseases occurring and handling of pesticides.

In Brazil, until decades ago, meteorological data were collected and filed, and monthly bulletins were developed about climatic conditions only at the end of each

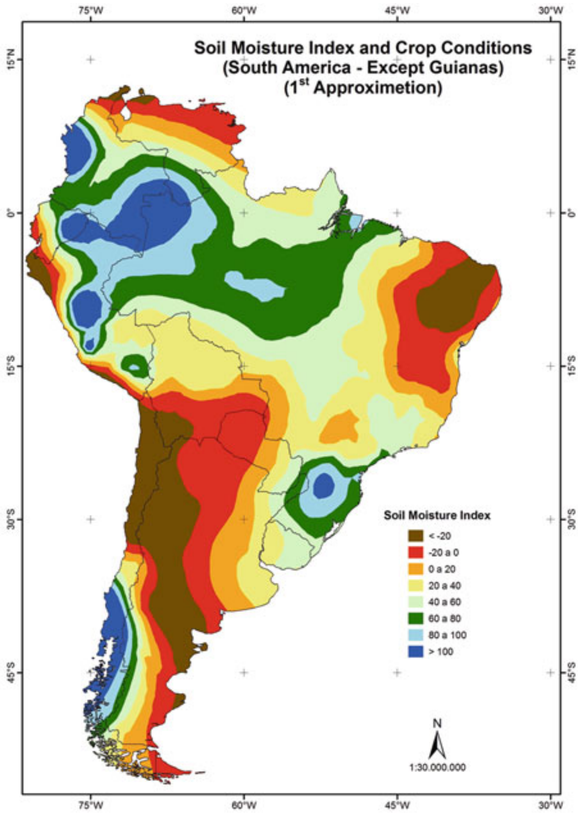


Fig. IV.23 Annual mean soil moisture index for South America, except for the Guianas (1st approximation)

month. They were used in general zoning and agricultural planning studies. The act of direct and everyday use of meteorological data in agricultural decision making, such as in planning and advising on agricultural practice, came into effect in 1988 with the creation of the Integrated Center of Agrometeorological Information (CIIAGRO) by the government of the State of Sao Paulo. Then the direct use of agrometeorological information in agricultural decision making began to be systematically applied to assist the use of agricultural and water resources (Brunini et al. 1998, 2003).

In Brazil, the agency responsible for the coordination of agrometeorology at a national level is the National Institute of Meteorology (INMET) (www.inmet.gov.br), where there is a special Department for agrometeorology, providing general information about climate conditions and plant development. Besides the fact that INMET is the official agency, associated with the World Meteorological Organization (OMM), this work and functioning is supported by various states through state secretaries or university and research institutes.

Among the work taking place in Brazil, The Agricultural Institute of Paraná, IAPAR (www.iapar.br) may be specifically mentioned, where agroclimatic monitoring for decision support emphasizes the following products:

- weekly analysis of agricultural crop conditions;
- daily maps of: rainfall (total for every 24 h); average, maximum, and minimum air temperatures; evapotranspiration; number of days without rain; water deficit/surplus; estimated water available in the soil;
- weekly maps of: rainfall; average, maximum, and minimum air temperatures; evapotranspiration;
- monthly maps of rainfall with deviations from historic averages;
- agroclimatic monitoring of coffee crops.

Furthermore, IAPAR has had a frost alert system since 1995. The purpose is to alert coffee farmers 48–24 h ahead of time of the occurrence of frost in the coffee region. It is this way possible to provide sufficient time for decision making to protect newly planted fields as well as seedling nurseries, avoiding losses to producers. Here the decision support becomes an agrometeorological service (see Parts I and II). The service is in place from May to September through telephone alerts, internet, and e-mails, as well as TV, radio, and newspaper bulletins throughout the state of Paraná.

Another example is CIRAM, created in 1998 by the government of the state of Santa Catarina, to support decision making on agricultural activities and the preservation of natural resources (www.epagri.rct-sc.br). In Rio Grande do Sul (www.fepagro.re.gov.br) this is done through the region's agrometeorological information system. The program's objective is the implementation of a network of automated meteorological stations for weather and climate monitoring in real time, making meteorological information available so that technical indications for decision making on climatic risk reduction can be sent to farmers and the extension service sector.

These indications make it possible to reduce the effects of climate variation on agricultural production, as well as to provide important information to irrigation projects, improving agricultural zoning and the implementation of the Agricultural Insurance Program in the state. In view of the effect of meteorological adversities on agricultural activities, studies have concentrated on the evaluation of climatic risks and agricultural insurance (Assad et al. 2003; Pinto et al. 2001; Zullo Jr. et al. 2000). They have been used for the definition of risk areas and establishment of agricultural insurance policies by the federal government. Figure IV.24 indicates this definition of risk for corn in the state of Sao Paulo (Brunini et al. 2001).

In Sao Paulo, main products for decision support in agricultural planning and farmers' activities are carried out by the Agronomic Institute, through CIIAGRO (www.ciiagro.sp.gov.br) and INFOSECA (www.infoseca.sp.gov.br). Agricultural decisions supported by CIIAGRO are related to the agricultural calendar, soil tillage, application of agricultural chemicals, irrigation monitoring, ripening dates and harvesting dates, control of pests and diseases, transportation of agricultural products, and forest operations related to fires, frosts, and other adverse phenomena. Weekly

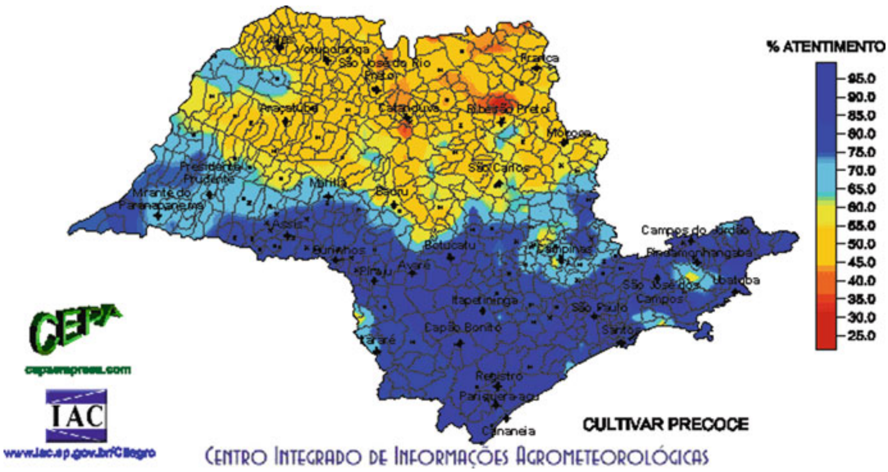


Fig. IV.24 Climatic risks and corn water requirement for a specific planting date

and monthly maps with corresponding deviations and anomalies from typical air temperature and rainfall are made available.

Information that can be reached on the websites refers to topics ranging from monitoring aspects and water balances of crops, to general summaries of the climatic conditions in the state of Sao Paulo (Brunini et al. 2006, 2008a). Besides this general support, information and specific decision support for farmers can be found, such as on the effect of the climate on pests and tropical crop diseases (Brunini et al. 2005), and adversity warnings of interest to civil defense (Brunini et al. 2007; Rolim et al. 2007). Specific to corn crops, the analysis of the three most important pests, army worm (*Spodoptera frugiperda*), corn rootworm (*Diabrotica speciosa*), grass spittlebugs (*Deois flavopicta*), is carried out and made available on the website (www.ciiagro.sp.gov.br/pragasdomilho). Where this is indicating favorable or unfavorable conditions for the development of pests, it has become an agrometeorological service. Figure IV.25 presents a general army worm warning.

Among this work on climate and its effect on pests and diseases are studies developed by Pedro Junior et al. (1999a, b) and Pezzopane et al. (1998). In the above work, emphasis is on peanut and grapevine crops. Concerning irrigation planning, INFOSECA has proven to be an excellent tool for irrigation tracking, irrigation planning, and irrigation prognosis (Brunini et al. 2008b). Irrigation requirements, soil moisture status and crop water satisfaction, with the meteorological prognosis, are presented in Fig. IV.26. This type of decision support is directly used by the irrigation association.

Regarding sugarcane crops, CIIAGRO (Brunini 1999) developed decision support that is now being used by various researchers and sugar mills, Agrometeorological Sugarcane Crop Monitoring System (SISCANA). This allows the tracking and prediction of different phenological stages of the crop, the harvesting season, flowering prognosis and irrigation needs.

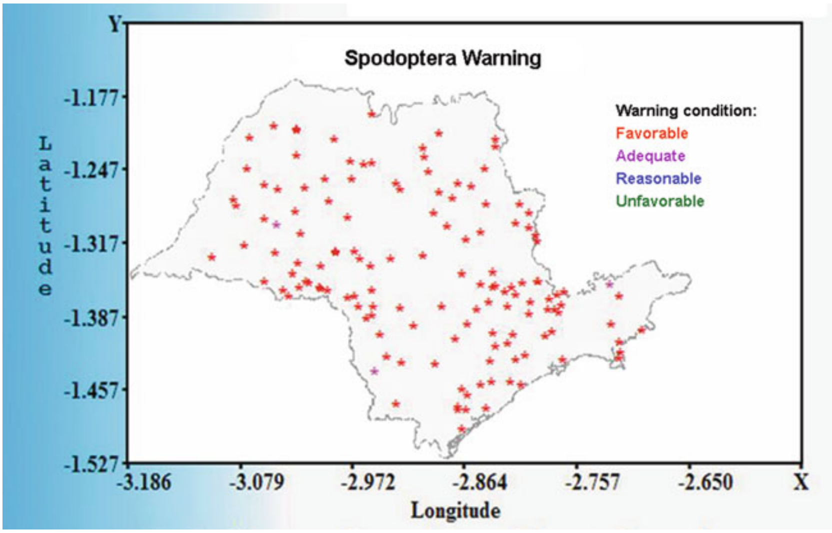


Fig. IV.25 Pest warning conditions for corn

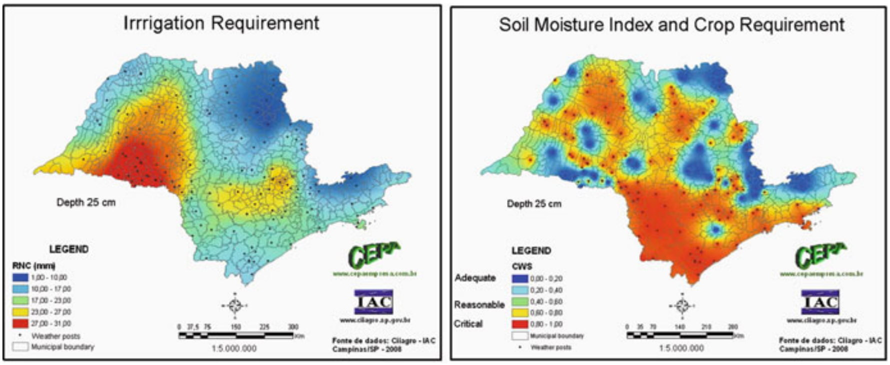


Fig. IV.26 Irrigation warning system for São Paulo State based on INFOSECA

Another product has been developed in Brazil, which clustered several institutions in various Brazilian states and even South America countries such as Columbia and Costa Rica, among others. Agrometeorological Monitoring Systems (SMAs) inform the farmer of weather conditions and their influence on crop development, and productivity. The SMAs supply information about weather conditions and whether they are favorable to the development of each phenological phase of coffee, as for example in the phytosanitary notification station MAPA/Procafé Foundation of Varginha (Japiassu et al. 2005).

Additionally, they can for example provide alerts of adverse events such as frost, Indian summer, and hail, which directly affect the productivity of the cropping area and fruit quality. This adds to the conclusion that for the coffee crop agrometeorological monitoring is an important tool in preparing decision support. It may assist a farmer's decision making such as determining the best periods for pruning and harvesting, irrigation needs, and protection against meteorological adversity. If the SMA is coupled with a system of phytosanitary control, producers can receive notification of disease risk such as for coffee rust (*Hemileia vastatrix*), coffee leafminer (*Perileucoptera coffeella*), coffee berry borer (*Hypothenemus hampei*) etc. which generally depend on weather conditions. With this, producers improve their application of agricultural pesticides, increasing profit and preserving the environment.

There are some international SMAs for coffee production areas: Instituto Meteorológico Nacional da Costa Rica (http://www.imn.ac.cr), Instituto de Hidrologia, Meteorologia y Estúdios Ambientales da Colômbia (http://www.ideam.gov.co), Índia Meteorological Department (http://www.imd.ernet.in) and Servicio Nacional de Meteorología e Hidrologia del Perú (http://www.senamhi.gob.pe).

There are even some SMAs with specific products for coffee cultivation such as: the agroclimatic monitoring in Paraná (http://www.iapar.br/Sma), agrometeorological coffee monitoring in the state of Sao Paulo (http://www.ciiagro.sp.gov.br) and the Cooperativa Regional de Cafeicultores de Guaxupé (https://www.cooxupe.com.br/meteorologia).

Given the aspects presented and described here, it is clear that although agrometeorology is of high interest in decision support for sustainable development of agriculture in South America, and relevant to food production programs, there is a lack of direct agrometeorological services and information that is immediately useful to and easily accessible and applicable by farmers and consultants. The process of training and improving the resilience of farmers and technical personnel should therefore also be a priority. Figure IV.27 shows demonstration classes dealing with the use and application of agrometeorological products and information in different environments.

Fig. IV.27 Training to use agrometeorological products in decision support to farmers' activities

References

Assad E, Macedo MA, Zullo Jr J, Pinto HS, Brunini O (2003) Evaluation of geostatistical methods specializing in agrometeorological rates for the definition of climatic risks. Braz Agric Res 38:161–171

Brunini O (1999) Agrometeorological monitoring system for sugar cane crop. Operating Software – Basic – Windows System/Linux. www.ciiagro.sp.gov.br

Brunini O, Caputi E (2001) Software for estimation of the water balance. Fundação de Apoio a Pesquisa Agrícola, São Paulo, Brazil. CDROM

Brunini O, Fujiwara M, Pires RCM, Pinto HS, Arruda FB (1998) Agrometeorological advising system. Proceedings of the 2nd Brazilian Biometeorology Congress, Goiânia. Soc Bras Biomet 2:15–37

Brunini O, Zullo Jr RJ, Pinto HS, Assad E, Sawasaki E, Paterniani MEZ (2001) Climatic risk to corn crops in the state of São Paulo. Rev Brasil Agrometeorol 9:519–526

Brunini O, Camargo MBP, Pedro Jr MJ, Abramides PLG, Blain GC, Brunini APC, Ernandes ES, Tremocoldi W (2003) Agrometeorological monitoring as agricultural decision making support. Proceedings of the XIIIth Brazilian Agrometeorology Congress, Santa Maria. Soc Bras Agrom 1:837–838

Brunini O, Abramides PLG, Pedro Jr MJ, Brunini APC, Ernandes E, Almeida EL (2005) Agrometeorological support for agrometeorological monitoring in the control of disease and pests of cultivated plants. In: Pests and diseases of Amazonian crops. Amazôn Orient 1:95–113

Brunini O, Abramides PLG, Camargo MBP, Pedro Jr MJ, Pezzopane JR, Brunini APC, Blain GC, Rolim GS, Ribeiro RV, Tremocoldi WA (2006) Agrometeorological warning system for São Paulo State, Brazil. Proceedings of the International Conference on Experiences on Automatic Weather Stations, Lisbon, 24–26 May. CDROM, Institute of Meteorology, Lisbon

Brunini O, Abramides PLG, Brunini APC, Saes LA, Sakai, M, Ikeda NAI, Nasshiro G (2007) Agrometeorological alert system in support of civil defense and agricultural activities. Proceedings of the 2nd Brazilian Symposium of Natural and Technical Disasters, CDROM, Santos

Brunini O, Abramides PLG, Prela A, Rolim GS, Blain GC, Ribeiro RV, Tremocoldi WA, Calheiros RV, Camargo MBP, Pedro Jr MJ (2008a) Hydrometeorological and environmental monitoring in the state of São Paulo – a CIIAGRO action. Rev Tecnol Inov Agropec 1:90–97

Brunini O, Abramides PLG, Carvalho JP, Brunini APC (2008b) INFOSECA in the planning and prognosis of irrigation and meteorological risks. In: Workshop Red Riegos, CYTED, Florianópolis. CDROM

Caramori PH, Oliveira D, Brunini O, Bergamaschi H, Braga HJ (2003) Operational agrometeorology diagnostics in Brazil. Rev Bras Agrometeorol 10:363–371

Japiassu LB, Garcia AWR, Miguel AE, Mendonça JMA, Carvalho CHS, Ferreira RA, Matiello JB (2005) The influence of overproduction, spacing, and climatic factors on the development of rust on coffee crops. Phytosanitary advisory station MAPA/Fundação Procafé, Varginha. Brazilian Symposium of Brazilian Coffee Research, Londrina. CDROM, EMBRAPA/Café, Brasilia

Pedro Jr. MJ, Pezzopane JRM, Abramides PLG, Ribeiro IJA, Martins FP (1999a) Indication of the spraying season for the control of fungal disease in Niagara Rosada vines, based on a phenological-rain gauging system. Rev Bras Agrometeorol 7:235–242

Pedro Jr MJ, Pezzopane JRM, Martins FP (1999b) The use of precipitation for the predicting of spraying periods aiming for the control of fungal disease in the Niagara Rosada vine. Rev Bras Agrometeorol 7:107–111

Pezzopane JRM, Pedro Júnior MJ, Moraes SA, Godoy IJ, Pereira JCVNA, Silveira LCP (1998) Rain and the prediction of periods for controlling peanut foliar spots. Bragantia 57:285–295

Pinto HS, Assad E, Zullo Jr J, Brunini O, Alfonsi RR, Coral G (2001) Zoning climatic risks for coffee cultivation in the state of São Paulo. Rev Bras Agrometeorol 9:495–500

Rolim GS, Pedro Jr MJ, Fantin GM, Brunini O, Duarte AP (2007) Agrometeorological model for estimating the intensity of Phaeosphaeria in corn crops in the State of São Paulo as a result of air temperature and rain. Bragantia 66:721–728

Thornthwaite CW, Mather JR (1955) The water balance. Publications in Climatology. Drexel Institute of Technology, Centerton, 104pp

Zullo Jr J, Pinto HS, Brunini O, Assad E, Pellegrino GQ, Camargo MBP (2000) Agriculture climatic risks in Sao Paulo State. In: IRI (ed) Climate prediction, agriculture and development. International Research Institute for Climate and Society (IRI), New York. CDROM

IV.14 Global Potentials for Greenhouse Gas Mitigation in Agriculture

Julian Dumanski, Raymond L. Desjardins, Rattan Lal, Pedro Luiz De Freitas, Pierre Gerber, Henning Steinfeld, Louis Verchot, Gerald E. Schuman, Justin D. Derner, and Mark Rosegrant

Improved management of agricultural lands and other terrestrial areas offers considerable potential to mitigate climate change. Currently, 83% of the world's land area is directly influenced by human interventions (Sanderson et al. 2002 cited in Kareiva et al. 2007), about half of the terrestrial earth's surface is extensively managed and 25% is intensively managed (UNEP 2005).

Agricultural lands, including arable land, permanent crops and pasture, occupy about 40% of the earth's land surface (FAO 2007), mostly under pasture and rangelands (∼70%), cropland (25%) and permanent crops (<3%). Estimates were that by rather early this century, all land would be under some degree of management (Vitousek 1994). How these lands are managed will impact directly on the potential for mitigation of climate change.

In terms of forcing agents for climate change, the Pew Centre (2006) reports that anthropogenic factors were relatively unimportant during the first few decades of the twentieth century (compared to changes in solar energy and volcanic activity), but anthropogenic greenhouse gasses (GHGs) assumed dominance during the last half of the century.

The Stern Review (Stern 2007) reports that current levels of GHGs in the atmosphere are approximately 430 ppm carbon dioxide equivalent (CO_2 e), and rising at more than 2 ppm each year. The Review emphasizes that risks of the worst impacts of climate change can be substantially reduced if greenhouse gas levels in the atmosphere can be stabilized between 450 and 550 ppm CO_2 e, but stabilization in this range requires that emissions be reduced by at least 25% below current levels by 2050. At the Bali conference there was repeated asking for 50% reduction by 2050 (e.g. Anderson and Bows 2008). More recent estimations from large social climate movements for a safe atmosphere even go as low as 350 ppm but Anderson and Bows (2008) indicate that by taking the trends between 2000 and 2008 into account,

J. Dumanski (✉)
Retired from Agriculture and Agri-Food Canada and World Bank, Ottawa, ON, Canada
e-mail: jdumanski@rogers.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_114,

even an optimistic interpretation suggests that stabilization much below 650 ppm is improbable.

Between 1970 and 2004, global emissions of GHGs increased by 70%, from close to 29–49 Gt CO_2 e. CO_2 emissions increased by about 80% and represented 77% of total anthropogenic GHG emissions. During this period, emissions from the energy supply sector increased by 145%, transport 120%, industry 65%, land use change, and forestry, 40%, and agriculture by 27% (IPCC 2007).

Agriculture and land use change are normally considered as non-energy emissions, and collectively these accounted for about 35% of total emissions (compared to industry, transport, power generation, etc.). China, India, Brazil, and the USA are clearly the largest polluters of non-CO_2 GHGs. Although the emissions from agriculture are relatively small, the mitigation of climate change requires that all sectors reduce their emissions to the atmosphere.

In addition to emission reductions, climate change can be mitigated by enhancing carbon sinks and promoting carbon sequestration, particularly in terrestrial and oceanic systems. Agriculture, along with forestry and land use change, can make significant contributions by removing carbon from the atmosphere through soil organic carbon sequestration (see Box IV.14), and by providing biomass for energy sources. The opportunity for improved sequestration arises because of the already degraded organic carbon status of most cultivated soils. Lackner (2003) estimated the global storage capacity of soil organic carbon at roughly 100 Gt C, slightly greater than the potential for carbon storage in woody biomass, and less than the potential for carbon storage in the ocean.

Box IV.14 (Contributed by R. Lal)

This Box deals with the potential for carbon sequestration in terrestrial systems. Increases in atmospheric concentration of CO_2 began 8,000 years ago, and that of CH_4 5,000 years ago (Ruddiman 2003, 2005). This corresponds with the conversion of grasslands, deforestation, soil cultivation, spread of rice paddies, and domestication of livestock involved with settled agriculture. He estimated pre-industrial emission (prior to 1750) of CO_2 from terrestrial ecosystems at $\sim$ 320 Pg, whereas post-industrial emission (1750–2000) is estimated at 270 Pg from fossil fuel combustion, and 136 Pg from land use change (IPCC 2000). Thus, emissions from terrestrial ecosystems have accumulated about 456 Pg or 114 ppm of CO_2 (1 ppm of atmospheric $CO_2 = 4$ Pg of CO_2 emission) since the onset of settled agriculture. This has resulted in temperature increases since 1950 of about 0.16°C/decade with a cumulative increase in temperature of 0.6 ± 0.2°C during the twentieth century (IPCC 2007).

Considering the historic carbon emissions from the atmosphere (114 ppm), and assuming that 40–50% of these can be re-sequestered, this amounts to off-setting atmospheric concentration by about 50 ppm over the next 50 years. Potentially, this is a huge contribution to mitigating climate change. Carbon sequestration in world soils and terrestrial ecosystems, compared with geologic and oceanic sequestration, is a natural and cost-effective win–win strategy, and a bridge to the future until low-C economies are developed and adopted.

There are already a large number of technical options for carbon sequestration in soils and terrestrial ecosystems. These include restoration of degraded and desertified soils through afforestation and reforestation, adoption of best management practices on cropland and grasslands, establishment of biofuel plantations (such as warm season grasses and short rotation woody perennials), and agroforestry. Each of these strategies has a potential carbon sink capacity of about 1 Pg C year^{-1} for the next 50 years (Pacala and Socolow 2004).

Soil carbon sequestration and an enhanced soil organic carbon pool have numerous ancillary benefits including: (i) increase in soil aggregation and improvement in soil tilth; (ii) decrease in risks of soil erosion by water and wind; (iii) increase in plant available water storage capacity; (iv) improvement in plant nutrient retention and availability; (v) increase in food/energy supply for soil organisms; (vi) biodegradation and denaturing of pollutants; (vii) purification of water; (viii) decrease in non-point source pollution; (ix) increase in biodiversity and (x) improved efficiency of fertilizer and irrigation waters. Thus, while mitigating climate change and improving the environment, soil carbon sequestration is also essential to advancing global food security. Lal (2006) estimated that an increase in the soil organic carbon pool by 1 Mg C ha^{-1} year^{-1} in degraded and desertified soils can lead to an increase in food production in developing countries by an additional 30–50 million tons year^{-1}, which is adequate to fill the food gap in Sub-Saharan Africa and elsewhere in the developing world (Shapouri and Rosen 2006).

Currently, soils in developing countries, particularly Sub-Saharan Africa and South Asia, are the most depleted of carbon and nutrient reserves, and thus have a large potential for carbon sequestration. However, and despite the higher potential and greater need, the challenge of soil organic carbon sequestration in these soils is also much greater than those in soils of temperate regions (Lal 2000, 2007).

"Mitigation potential", the extent of GHG reductions that may be possible for a given price of carbon can be described in several terms. "*Market potential*" is the mitigation potential which might occur considering current and forecasted markets, policies, programs, and existing barriers. "*Economic potential*" takes into account social costs, benefits, and discount rates, assuming that market efficiency is improved through improved policies and programs, and barriers are removed.

"*Technical potential*" is a theoretical potential assuming adoption of all technical options and no economic or policy barriers.

The technical potential for mitigation options in agriculture by 2030, considering all gasses, was estimated at 4.5–6.0 Gt CO_2 e (Caldeira et al. 2004; Smith et al. 2008). The economic potential, of course, is considerably lower. Mitigation potential should not be confused with "adaptation to climate change", which is the process of building resilience and minimizing the costs of climate change, assuming that climate change is inevitable (Stern 2007). Both processes are important and must be considered in developing strategies to deal with climate change.

The evidence is increasingly clear that global climate change is already occurring, and that strong mitigation measures are needed now to avoid serious impacts on the global economies. The Stern Review (Stern 2007) concludes that the concentration of GHGs in the atmosphere could reach double its pre-industrial level as early as 2035, in which case global average temperature rise may be 2 °C and perhaps as high as 5 °C. This rise in global temperatures is equivalent to the change in average temperatures from the last ice age to today.

Among the many indicators assembled by the Pew Centre (2006), they report that the six oceans that straddle the equator have been warming simultaneously for at least the past 40 years, and that the oceans have been warming from the surface downward. They also report on the clear patterns of global deterioration of ice cover, both for sea ice and land based glaciers, indicative of global warming. These and many other changes cannot be explained by regional differences, but require external forcing. The benefits of early action on mitigation far outweigh the continued costs of inaction.

The agriculture sector was once a major contributor to GHG emissions, but it has been superseded by the power and transportation sectors. However, all sectors have a role to play and all must be mobilized in the collective efforts to mitigate global climate change. Significantly, agriculture has an important role because of the large land areas involved, and because there are already many available technologies and opportunities in agriculture to contribute to the global mitigation effort, many of which can be implemented with minimal or no cost.

Although deforestation is often treated as an issue in forestland management, it is also an important link with land use change and the conversion of forested land to agriculture. Annual emissions from land use change during the 1990s, considering the collective impacts of CO_2, CH_4 (methane), and N_2O (nitrogen dioxide), accounted for about 20–25 % of the total anthropogenic emissions of GHGs (Houghton 2005). FAO (2005) estimates that about 15.4 million hectares of tropical forests were lost each year during the 1980s, 10.1 million hectares were lost annually from 1990 to 2000, and 10.4 million hectares were lost annually from 2000 to 2005.

Agricultural expansion was by far the leading cause at a global scale, whether through forest conversion for permanent crops, cattle ranching, shifting cultivation or colonization agriculture. The most prominent underlying causes of deforestation and degradation are economic factors, weak institutions and inadequate national policies, and other remote influences such as wood extraction, and road and infrastructure extension, that drive proximate causes of agricultural expansion.

References

Anderson K, Bows A (2008) Reframing the climate change challenge in light of post-2000 emission trends. Philos Transact A Math Phys Eng Sci 366(1882):3863–3882. http://www.ncbi.nlm.nih.gov/pubmed/18757271

Caldeira K, Morgan MG, Baldocchi D, Brewer PG, Chen CTA, Nabuurs GJ, Nakicenovic N, Robertson GP (2004) A portfolio of carbon management options. In Field CB, Raupach MR (eds) The Global Carbon Cycle. Integrating Humans, Climate, and the Natural World. SCOPE 62, Island Press, Washington, pp 103–129

FAO (2005) Global forest resources assessment. Progress towards sustainable forest management. FAO Forestry Paper 147, Rome. http://www.fao.org/DOCREP/008/a0400e/a0400e00.htm

FAO (2007) FAO Statistical Service. Rome. http://faostat.fao.org

Houghton RA (2005) Tropical deforestation as a source of greenhouse gas emissions. In: Moutinho P, Schwartzman S (eds) Tropical deforestation and climate change. Instituto de Pesquisa Ambiental, and Environmental Defense, Belen, Brazil; Washington, pp 13–21

IPCC (2000) Land-use, land-use change and forestry. Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, 375pp. http://www.ipcc.ch/ipccreports/sres/land_use/index.htm

IPCC (2007) Climate change: the physical science base. Cambridge University Press, Cambridge, UK. http://www.ipcc.ch/ipccreports/ar4-wg1.htm

Kareiva P, Watts S, McDonald R, Boucher T (2007) Domesticated nature: Shaping landscapes and ecosystems for human welfare. Science 29:316, 1866–1869

Lackner KS (2003) Climate change: a guide to CO_2 sequestration. Science 300(5626):1677–1678. http://www.sciencemag.org/cgi/content/short/300/5626/1677

Lal R (2000) Soil Management in developing countries. Soil Sci 165:57–72

Lal R (2006) Enhancing crop yields in developing countries through restoration of soil organic carbon pool in agricultural lands. Land Degrad Dev 17:197–209

Lal R (2007) Constraints to adopting no-till farming in developing countries. Soil Till Res 94:1–3

Pacala S, Socolow R (2004) Stabilization wedges: solving the climate problem for the next 50 years with current technologies. Science 305:968–972

Pew Centre (2006) E-Newsletter. Global fingerprints of greenhouse warming. A summary of recent scientific research. Compiled by Jay Gulledge. http://pewclimate.org

Ruddiman WF (2003) The anthropogenic greenhouse era began thousands of years ago. Clim Change 61:262–292

Ruddiman WF (2005) How did human first alter global climate? Sci Am 292:429–436

Shapouri S, Rosen S (2006) Soil degradation and food aid needs in low-income countries. In: R Lal (ed) Encyclopedia of soil science, 2nd edn. Taylor and Francis, Boca Raon, pp 425–427

Smith P, Martino D, Cai Z, Gwary D, Janzen HH, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes RJ, Sirotenko O, Howden M, McAllister T, Pan G, Romanenkov V, Schneider U, Towprayoon S, Wattenbach M, Smith JU (2008) Greenhouse gas mitigation in agriculture. Philos Trans R Soc, B 363:789–813

Stern N (2007) The economics of climate change. Cambridge University Press, Cambridge, 667pp. http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm

UNEP (2005) Millennium ecosystem assessment. UNEP. Nairobi, Kenya. http://www.un.org/News/Press/docs/2005/unep302.doc.htm

Vitousek PM (1994) Beyond global warming: ecology and global change. Ecology 75:1861–1876

IV.15 Strategies and Economies for Greenhouse Gas Mitigation in Agriculture

Julian Dumanski, Raymond L. Desjardins, Rattan Lal, Pedro Luiz De Freitas, Pierre Gerber, Henning Steinfeld, Louis Verchot, Gerald E. Schuman, Justin D. Derner, and Mark Rosegrant

Agriculture can make significant contributions to climate change mitigation by (a) increasing soil organic carbon (SOC) sinks, (b) reducing GHG emissions, and (c) off-setting fossil fuel by promoting biofuels. The latter has the potential to counterbalance fossil fuel emissions to some degree, but the overall impact is still uncertain compared to emissions of non-CO_2 GHGs, which are likely to increase as production systems intensify. Agricultural lands also remove CH_4 from the atmosphere by oxidation, though less than forestlands (Tate et al. 2006; Verchot et al. 2000), but this effect is small compared to other GHG fluxes (Smith and Conen 2004).

The main GHGs from agriculture are CO_2, CH_4, and N_2O, and collectively these account for 10–20% of the annual increase in radiative forcing, and up to one third when land use change is included (IPCC 2007). Agriculture accounts for between 59 and 63% of the world's non-CO_2 GHG emissions, including 84% of the global N_2O emissions and 54% of the global CH_4 emissions (USEPA 2006). Of these, N_2O emissions from soils are the most important, followed by CH_4 from enteric fermentation. Methane from rice cultivation is the third largest source. Deforestation is another major source of GHG emissions (about 7.6 Pg CO_2 e $year^{-1}$). Direct emissions from fossil fuel account for about 10% from this sector (Verchot 2007).

Non-CO_2 GHG emissions from agriculture are expected to increase significantly in the future, with soil emissions of N_2O (75%) and CH_4 from enteric fermentation (70%) being the largest sources. Enteric fermentation and emissions from manure are expected to increase significantly, and become about 50% greater than in 1990 (USEPA 2006). These emissions are driven by production pressures, which in turn are driven by global processes such as world population density, globalization, urbanization, increased purchasing power of the middle classes, etc (Dumanski 2008). Increased consumption of meat products as societies become more affluent is an important driver for emissions from enteric fermentation. All of these are expected to increase in the future, particularly in tropical countries.

J. Dumanski (✉)
Retired from Agriculture and Agri-Food Canada and World Bank, Ottawa, ON, Canada
e-mail: jdumanski@rogers.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_115,

Attention has recently focused on the role of agriculture to supply biomass for the production of ethanol and biodiesel. These are renewable energy sources with the potential to reduce emissions from fossil fuels, but there are concerns regarding the carbon efficiency of the process as well as possible negative impacts on soil erosion if residues are used for biofuels.

The Stern Review (Stern 2007) estimates that global mitigation of GHG emissions can be achieved with as little as 1% of global GDP if action is taken immediately. This, however, requires strong policy signals, including pricing of carbon (implemented through tax, trading or regulation), support for innovation and low-carbon technologies, and removal of barriers to energy efficiency. Although emphasis has to be on reductions in the power sector and transport, cuts in non-energy emissions, such as those resulting from deforestation and from agricultural and industrial processes, are also essential. While not as large as the potential from the power sector and transportation, the total potential savings from various agricultural and land use change activities are still substantial, and they can be achieved at a competitive cost.

Mitigation of GHGs in agriculture involves emission reductions, as well as carbon sequestration. Details on management aspects are in Box IV.15. Verchot (2007) estimates that some emission reductions can be achieved with no increase of implementation costs. Globally, approximately 7% of the net emissions from agriculture can be mitigated at a net benefit or at no cost, including approximately 15% from croplands, approximately 3% from rice cultivation, and 6% from animal production.

Box IV.15

Recently, there have been significant improvements in farm management practices with a resulting increase in the carbon efficiency of agricultural production. Notably, while N_2O and CH_4 emissions have increased because of increasing levels of food production, the GHG emissions per unit of production have decreased. In Canada, for example, GHG emissions per kilogram of beef cattle live weight are estimated to have decreased from 13.9 to 10.4 kg CO_2e from 1991 to 2006 (Vergé et al. 2008). During the same period, the GHG emission intensities for pork and poultry have decreased by 29 and 16% respectively (Vergé et al. 2009a, b).

Mitigation of climate change in agriculture requires adoption of integrated farming systems, since these capture the synergism of multiple practices and have the potential to reverse the decline and actually increase the soil organic carbon (SOC) pool. Practices such as zero tillage (ZT) have the combined effect of soil carbon sequestration while concurrently reducing fossil fuel use and improving biodiversity. Other mitigation measures include agronomic practices such as improved crop varieties, improved crop rotations, and improved fertilizer management. Better residue management and water management in rice can yield significant reductions of CH_4 emissions. For livestock, there are a wide range of practices associated with grazing land management, improved feeding, and manure management that can reduce emissions and increase carbon sequestration. The collective impact of these practices is to reduce GHG emissions and sequester carbon in the soil.

The IPCC (2000) identified three land use systems with significant global potentials for climate change mitigation, agroforestry, improved grassland management, and restoration of severely degraded lands. Verchot (2007) evaluated these options, and identified agroforestry and grassland management as the best options. Agroforestry involves the integration of trees into farming systems and agricultural landscapes, including the conversion of slash and burn to agroforests after deforestation, as well as conversion from low-productivity croplands to sequential agroforestry. Agroforestry has such a high potential because it is the land use category with the second highest carbon density after forests, and because there are large area suitable for such land use systems.

Improved grassland management, despite the low carbon densities in this land use system, has a high potential because of the large land areas suitable for these improvements (3.4 billion hectares). Improved carbon sequestration in grasslands can be achieved through introduction of more productive grass species and legumes, improved livestock management, proper stocking and improved nutrient management. About 60% of the grazing lands suitable for improved carbon sequestration are in developing countries (Verchot 2007). These land use systems are also effective in helping small scale farmers adapt to climate change, because they reduce their vulnerability to inter-annual weather variability and changing climatic conditions. Rehabilitation of degraded land and wetland restoration are very expensive, and globally they have limited potential for climate change mitigation, although they may have significant local benefits.

The mitigation potentials increase somewhat with an increase in the price of carbon. Approximately 20% of agricultural emissions can be mitigated as carbon prices approach \$30/t CO_2e (Verchot 2007). Beyond this point, the returns on investment decrease rapidly, suggesting that there are fewer opportunities for greater reductions at higher carbon prices. The greatest potentials for negative and low-cost reductions are in the Russian Federation, non-OECD countries, Australia/New Zealand, and the United States, with only moderate potential in most other countries.

Achieving significant carbon mitigation in developing countries will require tapping carbon offsets from agriculture and land use change. With as much as 13 Gt of CO_2 per year at prices of US\$10–20 per tons, this represents potential financial flows of US\$130–260 billion annually, comparable to annual official development assistance of US\$100 billion, and foreign direct investment in developing countries of US\$150 billion (Mark Rosegrant/IFPRI, personal communication).

Evidence for the conclusions in this paper can be found in Chap. IV.16, "Supporting evidence for greenhouse gas mitigation in agriculture". The opportunities for enhanced carbon sequestration in soils arise because of the degraded carbon stocks in most cultivated soils. However, the sequestration potentials vary according to soil type and ecosystems. Soil carbon sequestration will continue only to the point where a new carbon equilibrium is reached. In all probability, this new level will be lower than the original carbon stock, and to a large extent it will be highly controlled by specific land management practices and inputs, operating within specific soil types and local environments. Although soil carbon sequestration has considerable potential to mitigate climate change, increases in SOC are often associated with increases in N_2O emissions, which act to counterbalance the sequestration benefits. Soils with higher SOC generally have higher N_2O emissions (Grant et al. 2004).

Spatial and temporal variability associated with the biophysical environment and variation in farm management systems remain major problems for monitoring, evaluation, and certification of soil carbon sequestration. The agricultural sector consists of many millions of small and large scale entrepreneurs (individual decision makers), each of which use specific management strategies to optimize their enterprises on their specific land holdings. Although there are common threads among these multitudes, the dual constraints of spatial variability due to varying land areas and those of varying management practices generates significant difficulties in monitoring the progress of mitigation.

Generally, progress has been made in estimating soil carbon sequestration, but the estimation of the non-CO_2 GHGs like N_2O and CH_4 remains problematic. In terms of mitigation potentials, this is particularly important since carbon and nitrogen move in coupled biogeochemical cycles in nature, and increased soil carbon sequestration often results in increased N_2O emissions, thus negating somewhat the mitigation benefits.

Soil carbon sequestration has a higher mitigation potential than emission reductions in agriculture, although both are important. These are best achieved under management systems with higher carbon density, as well as improved soil conservation. Also, enhanced soil carbon pools provide numerous agronomic and environmental benefits, and stabilize global nutrient cycles, with the resultant long-term enhancement of the resilience of agricultural systems to climate change. There are lingering uncertainties on the permanence of the sequestered carbon and on the potentials for leakage, but permanence can be assured by promoting land management philosophies such as sustainable land management that enhance economic viability while also sequestering carbon. It can also be assured through agronomic practices that "inject" more carbon at depth, using more deep rooting cultivars.

On a global scale, grassland management, agroforestry, integrated ZT technologies (Conservation Agriculture), and reduced GHG emissions from animal production have emerged as the strategies with the highest potentials for GHG mitigation in agriculture. These arise because of the large land areas suitable for these land uses, the high carbon density in agroforestry systems, and the increased carbon sequestration capacity under ZT systems. Important emission reductions can also be achieved through improved fertilizer and soil nitrogen management. Also, crops and crop residues can be used as source material for ethanol and bio-diesel, to reduce the use of fossil fuels. However, the social issues and equity issues involved with bioenergy still have to be worked out. Use of agricultural land for biomass production for energy can have implications for food security as well as positive and negative environmental impacts.

The lack of an effective carbon price is currently one of the most significant detriments to collective global action. There are some strong trends in the expansion of global carbon trading, and some initiatives to promote carbon taxes. These are positive, since ultimately they will promote a realistic price on carbon. However, some key constraints still need to be overcome, namely how to mobilize the large and highly diverse global farm populations. And how to certify sequestered carbon and GHG emission reductions, given the high variability inherent in agricultural production environments?

In addition, the rules of access to the benefits of carbon trading need to be streamlined, particularly for avoiding deforestation and stimulating soil carbon sequestration, as well as reducing the transaction costs for large and small initiatives which collectively will result in mitigation of climate change. There are no magic bullets, but the collective impacts of many similar initiatives, by small and large scale farmers, can produce significant results in mitigating climate change, while simultaneously enhancing the resilience of the agricultural sector to adapt to the climate change that is already occurring.

References

Dumanski J (2008) Commentary: The changing face of soil and water conservation. Keynote Presentation from the XVII Meeting of the Brazilian Society for Management and Conservation of Soil and Water, Rio de Janeiro, August

Grant B, Smith W, Desjardins RL, Lemke R, Li C (2004) Estimated N_2O and CO_2 emissions as influenced by agricultural practices in Canada. Clim Change 65:315–332

IPCC (2000) Land-use, land-use change and forestry. Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, 375pp. http://www.ipcc.ch/ipccreports/sres/land_use/index.htm

IPCC (2007) Climate change: the physical science base. Cambridge University Press, Cambridge. http://www.ipcc.ch/ipccreports/ar4-wg1.htm

Smith KA, Conen F (2004) Impacts of land management on fluxes of trace greenhouse gases. Soil Use Manag 20:255–263

Stern N (2007) The economics of climate change. Cambridge University Press, Cambridge, 667pp. http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm

Tate KR, Ross DJ, Scott NA, Rodda NJ, Townsend JA, Arnold GC (2006) Postharvest patterns of carbon dioxide production, methane uptake and nitrous oxide production in a Pinus radiata D. Don plantation. For Ecol Manag 228:40–50

USEPA (2006) Global mitigation of non-CO_2 greenhouse gases. US Environmental Protection Agency (USEPA), Washington. http://www.iiasa.ac.at/Research/ECS/IEW2006/docs/2006PPT_Fawcett.pdf

Verchot LV (2007) Opportunities for climate change mitigation in agriculture. A report to the UNFCCC Secretariat. Financial and Technical Support Programme. unfccc.int/files/cooperation_and_support/financial_mechanism/application/pdf/verchot.pdf
Verchot LV, Davidson EA, Cattânio JH, Ackerman IL (2000) Land-use change and biogeochemical controls of methane fluxes in soils of eastern Amazonia. Ecosystem 3:41–56
Vergé XPC, Dyer JA, Desjardins RL, Worth D (2008) Greenhouse gas emissions from the Canadian beef industry. Agric Syst 98:126–134
Vergé XPC, Dyer JA, Desjardins RL, Worth D (2009a) Greenhouse gas emissions from the Canadian pork industry. Livest Sci 121:92–101
Vergé XPC, Dyer JA, Desjardins RL, Worth D (2009b) Long-term trends in greenhouse gas emissions from the Canadian poultry industry. J Appl Poultry Res, 18:210–222

IV.16 Supporting Evidence for Greenhouse Gas Mitigation in Agriculture

Julian Dumanski, Raymond L. Desjardins, Rattan Lal, and Mark Rosegrant

The options for GHG mitigation discussed in the four Boxes IV.16, IV.17, IV.18 and IV.19 are agricultural systems with the highest potentials: agroforestry, rangeland management, zero tillage, and livestock production. Undoubtedly, other options may provide benefits in local situations, but recent evidence indicates that these farming systems provide the best opportunities.

Box IV.16 (Contributed by L. Verchot)

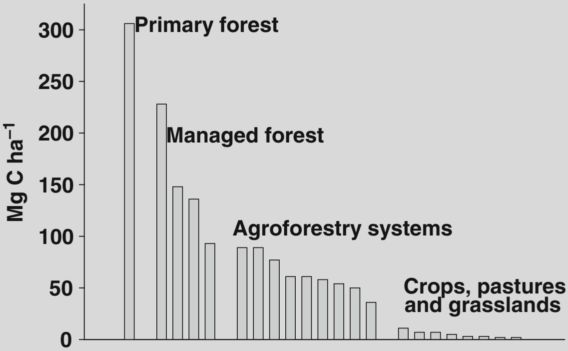
Agroforestry systems in the humid tropics include various types of tree-based production systems. Research in these areas (Palm et al. 2002) showed that conversion of primary tropical forests to cropland or grassland resulted in the loss of about 310 Mg C ha^{-1}, with managed or logged forests having only about half the C stocks of primary forests. Agroforestry systems contained 50–75 Mg C ha^{-1} compared to row crop systems with < 10 Mg C ha^{-1}. These results show that converting row crops or pastures to agroforestry systems can greatly enhance the C stored in above and below ground biomass. [Literature referred to in Sect. III.5.5.(γ) however cautions against too big expectations.]

Agroforestry also compares well with other land uses with respect to other GHGs. In Sumatra, a jungle rubber system had lower N_2O emissions than a primary forest, but also lower CH_4 uptake (Tsuruta et al. 2000). However, agroforestry systems such as multi-storey coffee with a leguminous tree shade canopy had N_2O emissions five times higher than open-grown coffee and about half the CH_4 uptake (Verchot 2007). In Peru, agroforestry systems (multistrata coffee and a peach palm plantation) with leguminous cover crops had lower N_2O emissions than both intensive and low-input agriculture and similar emissions to a nearby secondary forest (Palm et al. 2002). Soil uptake of

J. Dumanski (✉)
Retired from Agriculture and Agri-Food Canada and World Bank, Ottawa, ON, Canada
e-mail: jdumanski@rogers.com

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_116,

CH_4 was similar to other land use systems, with the exception of an intensive agriculture site, which became a net source to the atmosphere.



Agroforestry also has an important carbon sequestration role to play in the sub-humid tropics. Improved tree-based fallow rotations between cereal crops and tree-legume fallows have high potential to sequester C in both the aboveground biomass and the soil. Belowground C storage in these systems represents the potential for long-term C storage, as long as trees remain in the rotation, but the storage capacity is largely dependent upon soil texture and total rainfall. Coppicing fallows are newer, but follow similar trends. While these systems are cut frequently, the average aboveground carbon stocks exceed stocks in degraded land, cropland or pastures. Nitrous oxide emissions following the leguminous tree fallows was found to be almost 10 times that of unfertilized maize (Chikowo et al. 2003) but these levels were still extremely low in comparison to the amount of C stored.

Restoration of degraded land using improved tree fallows has the potential not only to sequester significant amounts of C from the atmosphere, it also offers opportunities for improving rural livelihoods by turning unproductive land into productive land that can produce food, wood and other tree products, and generate income. Typically, there are trade-offs between carbon stored and on-farm profitability, and while high carbon and high profit land uses have not yet been identified, several no regret options with medium to high profit and medium carbon stocks are already available, and could be implemented as a component in climate change mitigation schemes.

Box IV.17 (Contributed by G.E. Schuman and J.D. Derner)

Rangelands have a large potential for GHG mitigation because of the large global land area represented, even though the increase of soil carbon per unit of land is small (estimated as 0.02–0.20 Mg C ha^{-1} $year^{-1}$; Lal 2000). Globally, rangelands are estimated to contain 10–30% of the global SOC (Scurlock and Hall 1998). Schuman et al. (2001) estimated that improved management on 113 Mha of poorly managed rangelands in the US could sequester an additional 11 Tg of C annually. In addition, they estimated that the loss of 43 Tg C $year^{-1}$ could be avoided through the continued use of sustainable grazing practices, conservation of undisturbed native rangelands, and restoration of marginal croplands to perennial grasslands.

Soil C storage in rangelands is influenced by climate, biome type, rangeland management including grazing, N inputs and restoration, and environmental conditions such as drought, and climate change. Grazing management can influence rates of soil C sequestration by facilitating physiological breakdown, soil incorporation and rate of decomposition of plant materials. Grazing on a shortgrass steppe increased SOC in the top 30 cm of the soil compared to adjacent non-grazed exclosures by 0.12 and 0.07 Mg C ha^{-1} $year^{-1}$ for moderate and heavy stocking rates, respectively (Derner et al. 1997, 2006; Reeder et al. 2004). Also, grazing at light or heavy stocking rates in a northern mixed grass prairie increased SOC in the top 30 cm of the soil by 0.30 Mg C ha^{-1} $year^{-1}$ compared to non-grazed exclosures (Schuman et al. 2001). Improvement of soil N status in rangelands can be achieved by interseeding legumes into these systems. For example Mortenson et al. (2004, 2005) reported that interseeding of alfalfa (*Medicago sativa* ssp. *falcata*) into northern mixed grass rangelands significantly increased total forage production and increased SOC from 0.33 to 1.56 Mg C ha^{-1} $year^{-1}$. The use of legumes to enhance the N status of the soil can be achieved without the risk of increased N_2O emissions (Schuman et al. 2004). However, reduced SOC sequestration can be expected with longevity in grazing practices (Derner and Schuman 2007), consistent with other observations that ecosystems reach a new “steady-state” normally at levels lower than the original.

Climate, especially precipitation, can significantly impact C sequestration in rangelands, with SOC generally increasing with increasing precipitation; SOC in mesic rangelands can be 2–3 times higher than those in semi-arid rangelands (Derner et al. 2006). However, changes in precipitation and droughts may change rangelands from sinks to sources of CO_2. Ingram et al. (2008) reported that several years of severe drought resulted in a loss of SOC from soil of a northern mixed grass prairie that had been storing SOC for the previous 11 years. Also, C sequestration rates (in the top 30 cm of soil) have been shown to go from positive to negative with approximately $>$440 mm of precipitation (Derner and Schuman 2007).

Box IV.18 (Contributed by P.L. De Freitas and J.N. Landers)

Zero tillage (ZT) involves direct placement of seeds into the residues of the previous crop. However, refined procedures of ZT, called integrated ZT (Conservation Agriculture), includes maintenance of crop rotations, integrated pest and weed management, use of modern varieties and cultivars, careful and selective crop fertilization systems, and many other conservation technologies (De Machado and De Freitas 2003). The collective impacts of these technologies are increased soil carbon sequestration, reduced emission of non-CO_2 gases, and improved economic and environmental sustainability of agriculture in the tropics and sub-tropics. By removing CO_2 from the atmosphere, ZT technologies reduce the impacts of climate change.
Based on Brazilian conditions, soil carbon sequestration in grain crops grown under ZT can be approximately 350 kgC $ha^{-1}year^{-1}$ to a depth of 20 cm in tropical savannahs, and up to about 480 kgC $ha^{-1}year^{-1}$ in sub-tropical regions (Bayer et al. 2006). Considering the area already under ZT in Brazil, this can result in carbon sequestration of 29–40 Tg $year^{-1}$. However, considering the growth potential of ZT in Brazil, up to about 100 million hectares, and including the potential for production of ethanol and biodiesel, this could result in C sequestration in the order of 130–175 Tg of CO_2 $year^{-1}$ (De Freitas et al. 2007). This potential corresponds to 3–13% of all CO_2 currently emitted by deforestation and land use change (estimated at 1.4–4.3 Pg of CO_2). In temperate regions, ZT has been shown to remove small amounts of CH_4 from the atmosphere, but N_2O emissions are sometimes higher (Six et al. 2002).

Other benefits of ZT technologies are reduced emissions of GHG to the atmosphere, which accrue because of reduced use of fossil fuels for crop production, reduced use of chemical fertilizers and reduced N_2O emissions, reduced use of pesticides, and reduced soil erosion. Also, by capturing the synergy with other conservation technologies, ZT along with crop rotations promotes reduced CH_4 emissions in rice production, and CH_4 reductions in livestock enterprises, when combined with improved pasture and fertilizer management. In addition, ZT technologies have been used successfully to reduce residue burning in sugar cane production, thus reducing GHG emissions and air pollution (De Luca et al. 2008). The impacts of these, however, are considerably lower than those obtained through carbon sequestration (Verchot 2007).

Integrated ZT has been shown to improve the economic sustainability of both large and small holder agriculture. It has also been shown to considerably reduce off-farm externalities, such as soil erosion and silt control, public expenditures for infrastructure maintenance. It improved water filtration and aquifer recharge, local biodiversity and mitigation of drought. Some estimates for Brazil show that through the integration of crop and cattle enterprises under combined ZT and conservation principles, it may be possible to increase grain, fibre and meat production in Brazil to meet market demands for the next 20 years or more without further deforestation in frontier areas (Landers and De Freitas 2001).

Box IV.19 (Contributed by P. Gerber and H. Steinfeld)

The livestock sector is characterized globally by two contrasting production systems, (a) the rapidly growing industrial systems of pig and poultry production, (b) extensive and backyard production, mostly ruminants. Livestock production is an important form of income diversification, but for the very poor and those populations without land resources, it is often the only source of income. People living in marginal environments would not survive without their animals.

Livestock production often imposes a substantial environmental footprint, affecting climate, water resources and biodiversity in major ways. When taking into account the entire livestock commodity chain, from land use and feed production, to livestock waste and product processing, livestock production contributes about 18% of the total anthropogenic GHG emissions. Along the animal food chain, the main sources of emissions are:

- Land use and land use change: 2.5Gt CO_2e; including deforestation and conversion of natural grasslands to pasture and feed crops in the tropics and sub-tropics (CO_2) and carbon release from soils during cultivation (CO_2).
- Feed production: 0.4 Gt CO_2e, including fossil fuel used in manufacturing fertilizers (CO_2) and chemical fertilizer application on feed crops (N_2O, NH_3).
- Animal production: 1.9 Gt CO_2e, including enteric fermentation from ruminants (CH_4) and on-farm fossil fuel use (CO_2).
- Manure management: 2.2 Gt CO_2e, mainly through manure storage, manure application and manure deposition (CH_4, N_2O, NH_3).
- Processing and international transport: 0.03 Gt CO_2e.

Livestock related emissions are highest for beef and lowest for poultry, they are often diffuse and indirect, and occur at both the high and low end of the intensity spectrum. On average, extensive production has higher emissions per unit of output.

These high emission levels provide opportunities for GHG mitigation by the livestock sector, with often higher cost efficiency than in other sectors. Carbon-dioxide emissions can be limited by reducing deforestation, as well as by application of rangeland management practices such as: restoring organic carbon in cultivated soils, reversing soil organic carbon losses from degraded pastures, and sequestration through agroforestry. Improved livestock diets and better manure management can substantially reduce methane emissions, while careful nutrient management (i.e. fertilization, feeding and waste recycling) can mitigate nitrous oxide emissions and ammonia volatilization. Other opportunities, such as soil carbon in pastoral systems have not yet been exploited because of knowledge and institutional constraints but could potentially supply considerable offsets.

The use of biogas technologies can provide environmental benefits by redirecting emissions from manure management and reducing fossil fuel consumption, while simultaneously reducing on-farm expenses (e.g. from savings on energy bills, electricity trading). Already, private investors have used biogas within the framework of carbon trading projects within the CDM.

Global carbon trading will increase in the future, but two key constraints need to be overcome before significant benefits can be channeled to rural areas in developing countries (a) the rules of access must change, since these still do not credit developing countries for reducing emissions by avoiding deforestation or improving soil carbon sequestration, (b) the operational rules, with their high transaction costs for developing countries and small farmers and foresters in particular, must be streamlined.

Clean Development Mechanism (CDM) rules should encourage the participation of small farmers and community forest and agroforestry producers, and protect them against major livelihood risks, while still meeting investor needs and rigorously ensured carbon offset goals. This can be supported by:

- *Broadening the definition of afforestation and reforestation*. Agroforestry, assisted natural regeneration, forest rehabilitation, forest gardens, and improved forest fallow projects should all be eligible under CDM, because they offer low-cost approaches to carbon sequestration, while offering fewer social risks and significant community benefits and biodiversity benefits. Short-duration tree-growing activities should be permitted, with suitable discounting. Unfairly favoring large plantations should be avoided.
- *Promoting measures to reduce transaction costs*. Rigorous, but simplified procedures, as typified by the Chicago Climate Exchange, should be adapted to developing country carbon offset projects. Small-scale projects can benefit from simplified ways of determining baselines and monitoring carbon emissions. Small-scale agroforestry and soil carbon sequestration projects should be eligible for simplified modalities to reduce the costs of these projects. The permanence requirement for carbon sequestration should be revised to allow shorter term contracts, or contracts that pay based on the amount of carbon saved per year, which would avoid the need for "locking up" land in forest land uses for prolonged periods.

- *Establishing international capacity building and advisory services*. The successful promotion of livelihood enhancing CDM sequestration projects will require investment in capacity-building and advisory services for potential investors, project designers and managers, national policy makers, and leaders of local organizations and federations. Regional centers should be established to assist countries and communities involved in forest carbon trading. Institutional innovations can provide economies of scale and specialization. Companies or agencies can provide specialized business services for low-income producers to help them negotiate deals or design monitoring systems. Locally accountable intermediary organizations can manage projects and mediate between investors and local people.

Additional investment in advanced measurement and monitoring can dramatically reduce transaction costs. Measurement and monitoring techniques have been improving rapidly thanks to a growing body of field measurements and the use of statistics and computer modeling, remote sensing, global positioning systems, and geographic information systems, so that changes in stocks of carbon can now be estimated more accurately at lower cost.

References

Bayer C, Martin-Neto L, Mielniczuk J, Pavinato A, Dieckow J (2006) Carbon sequestration in two Brazilian Cerrado soils under no-till. Soil Till Res 86:237–345

Chikowo R, Mapfumo P, Nyamugafata P, Giller KE (2003) Mineral N dynamics, leaching and nitrous oxide losses under maize following two-year improved fallows on a sandy loam soil in Zimbabwe. Plant Soil 259:315–330

De Freitas PL, Martin-Neto L, Manzatto CV (2007) Solos: além de tudo, seqüestro de carbono [Soils: besides all, carbon sequestration]. In: Rev Agroanal, Fundação Getúlio Vargas, Rio de Janeiro, Brazil. Caderno Especial: Serviços ambientais no negócio agrícola [Special Anex: Environmental services in agribusiness] 2(4):E15–E16. www.agroanalysis.com.br/index.php?area=conteudo& esp_id=12& from=especial& epc_id=83

De Luca EF, Feller C, Cerri CC, Barthès B, Chaplot V, Campos DC, Manechini C (2008) Avaliação de atributos físicos e estoques de carbono e nitrogênio em solos com queima e sem queima de canavial. [Evaluation of physical properties and soil carbon and nitrogen stocks as affected by burning or green trash management of sugarcane] Rev Bras Ciênc Solo (Viçosa, Brasil) 32:789–800

De Machado PLO, De Freitas PL (2003) No till farming in Brazil and its impact on food security and environmental quality. In: Lal R, Hobbs P, Uphoff N, Hansen D (eds) Sustainable agriculture and the rice-wheat system. Marcel Dekker, New York, pp 291–310

Derner JD, Schuman GE (2007) Carbon sequestration and rangelands: a synthesis of land management and precipitation effects. J Soil Water Conservation 62:77–85

Derner JD, Briske DD, Boutton TW (1997) Does grazing mediate soil carbon and nitrogen accumulation beneath C_4 perennial grasses along an environmental gradient? Plant Soil 191:147–156

Derner JD, Boutton TW, Briske DD (2006) Grazing and ecosystem carbon storage in the North American great plains. Plant Soil 280:77–90

Ingram LJ, Stahl PD, Schuman GE, Buyer JS, Vance GF, Ganjegunte GK, Welker JM, Derner JD (2008) Grazing impacts on soil carbon and microbial communities in a mixed-grass ecosystem. Soil Sci Soc Am J 72:939–948

Lal R (2000) Soil management in developing countries. Soil Sci 165:57–72

Landers JN, De Freitas PL (2001) Preservação da vegetação nativa nos trópicos Brasileiros por incentivos econômicos aos sistemas de integração lavoura x pecuária com plantio direto. [Preservation of the natural vegetation in the Brazilian tropics by economic incentive to integrate crop/livestock ley farming with zero tillage adoption] In: Encontro Nacional da Sociedade Brasileira de Economia Ecológica–ECOECO 4. [Fourth National Meeting of the Brazilian Society for Ecological Economics], Belém, Brazil, Mesa Redonda 3–CDRom, np [Round Table 3–CDRom, no page reference]. www.ecoeco.org.br/conteudo/publicacoes/encontros/iv_en/mesa3/10.pdf

Mortenson MC, Schuman GE, Ingram LJ (2004) Carbon sequestration in rangelands interseeded with yellow-flowering alfalfa (*Medicago sativa* ssp. *falcata*). Environ Manag 33:S475–S48

Mortenson MC, Schuman GE, Ingram LJ, Nayigihugu V, Hess BW (2005) Forage production and quality of a mixed-grass rangeland interseeded with *Medicago sativa* ssp. *falcata*. Rangel Ecol Manag 58:505–513

Palm CA, Alegre JC, Arevalo L, Mutuo PK, Mosier AR, Coe R (2002) Nitrous oxide and methane fluxes in six different land use systems. Glob Biogeochem Cycl 16:1073

Reeder JD, Schuman GE, Morgan JA, LeCain DA (2004) Response of organic and inorganic carbon and nitrogen to long-term grazing of the shortgrass steppe. Environ Manag 33:S485–S495

Schuman GE, Herrick JE, Janzen HH (2001) The dynamics of soil carbon in rangeland. In: Follett RF, Kimble JM, Lal R (eds) The potential of US grazing lands to sequester carbon and mitigate the greenhouse effect. Lewis Publisher, Boca Raton, pp 267–290

Schuman GE, Ingram LJ, Parkin TA (2004) Nitrous oxide emissions from a northern mixed-grass rangeland interseeded with yellow-flowering alfalfa (*Medicago sativa* ssp. *falcata*). Society for Range Management Abstracts, Salt Lake City, Abstract #323, p 180

Scurlock JM, Hall DO (1998) The global carbon sink: a grassland perspective. Glob Change Biol 4:229–233

Six J, Feller C, Denef K, Ogle SM, De Moraes Sa JC, Albrecht A (2002) Soil organic matter, biota and aggregation in temperate and tropical soils—effects of no-tillage. Agronomie 22:755–775

Tsuruta H, Ishizuka S, Ueda S, Murdiyarso D (2000) Seasonal and spatial variations of CO_2, CH_4, and N_2O fluxes from the surface soils in different forms of land-use/cover in Jambi, Sumatra. In: Murdiyarso D, Tsuruta H (eds) The impacts of land-use/cover change on greenhouse gas emissions in Tropical Asia, Global Change Impacts Centre for Southeast Asia and National Institute of Agro-Environmental Sciences, IC-SEA. Bogor, Indonesia and NIAES, Tsukuba, pp 7–30

Verchot LV (2007) Opportunities for climate change mitigation in agriculture. A report to the UNFCCC Secretariat. Financial and Technical Support Programme. unfccc.int/files/cooperation_and_support/financial_mechanism/application/pdf/verchot.pdf

IV.17 Modeling and Simulation

Tomáš Orfánus

Experiments conducted for better understanding the mechanism of processes in environmental systems require usually a long time and large finances (Merdun 2006; Kňava et al. 2008). Models, as complementary tools, are simplified versions of the real systems (prototypes) and none of them can either represent the real processes in the real systems in sufficient detail or be assumed universal (Rosbjerg and Madsen 2005) due to complexity and scale dependence of involved processes, their natural variability and purpose of the modeling itself. Classifications are given in Box IV.20.

Box IV.20

Modern classifications of models are rather purpose built. Models can be sorted in different ways, for example (Addiscott and Wagenet 1985) deterministic versus stochastic, mechanistic versus functional, analytical versus numerical. See also Stigter (1994). In deterministic models, the set of input parameters results in a unique outcome, whereas stochastic models presuppose non-uniqueness of inputs and an outcome with uncertainty. Most of the flow and transport models are deterministic (Merdun 2006). Mechanistic models consider the most fundamental parts, processes and mechanisms of the system, whereas functional models are simplifying processes (Stigter 1994). Functional models are mostly used for management purposes while mechanistic models are used in science. Analytical models provide direct (closed form) solutions of governing flow and transport equations under defined initial and boundary conditions. Numerical models use some sort of numerical time-stepping procedure (finite difference or finite element) to get the solutions over time. Other classification (Solomatine 2005) distinguishes physical, mathematical (physically based = theoretical in Klemeš 2000), empirical (black-box) and combined (complementary and hybrid) models.

T. Orfánus (✉)
Institute of Hydrology, Slovak Academy of Sciences, Bratislava, Slovakia
e-mail: orfanus@uh.savba.sk

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_117,

"Mathematical models" is an upgraded term for "computational methods", which was brought about by the advent of the computer and the consequent "mathematization" of many kinds of analytical and technical work (Klemeš 2000). Thus, fast computers or other technologies may be utilized in the solution of complex and urgent environmental and/or food production problems in less time and with less expenses. The important question, therefore, which arises when we analyze the state of the art in agrometeorological modeling and simulations, is to what extent they are able to provide solutions to these problems.

Modeling can be perceived mainly as a framework for testing new theories and hypotheses in order to improve our understanding. For a good mathematical model, however, it is not enough to work well. A good fit of a model to measured data is often only a result of over-parameterization of the different processes involved. The model must work well for the right reasons (Klemeš 2000). Otherwise, we are still in the danger aptly formulated by Welles (1984), that "(. . .) our technological successes have simply made us more efficient at being stupid". Some more requirements are in Box IV.21.

Box IV.21

Comprehensive models have to be constructed using expert judgments (see also Chap. IV.4) to satisfy many constraints and requirements. Overarching considerations are the accurate simulation of the most important subject features and the scientific understanding of the processes that control these features (Klemeš 2000; Bader et al. 2008). Typically, the basic requirement is that models should simulate features important to humans but a physically based model also must simulate all complex interactions in the coupled systems manifested as variables of interest. Thus, comprehensive models should produce correctly not just the means of variables of interest but also the extremes and other measures of natural variability. Finally, the models should be capable of simulating changes in statistics caused by relatively small changes in e.g. the Earth's energy budget that result from natural and human actions (Bader et al. 2008).

It is recommended that modeling studies should include the phases of: (a) determination of a general or site-specific problem, (b) conceptualising important properties, processes, and events, (c) quantitative definition of the problem or developing and validating a computer code, (d) calibration of the model and collection of independent data for evaluating its prediction capabilities, and (e) developing new prediction techniques in order to solve the defined problem (Anonymous 2001 cited by Merdun 2006; Rosbjerg and Madsen 2005).

Available data for a site and combining the scientific knowledge with the experience (expert knowledge) play a significant role in determination of factors important for the problem. Different alternative hypotheses should be evaluated during the design of the model and using various data should test its relevance and accuracy. Appropriate mathematical/numerical formulation corresponding to the chosen temporal and spatial discretization must be given. For estimation of model parameter values, sensitivity analyses of the model should be made and then parameters of the model should be calibrated. Models should be tested using the data unused in the calibration procedure (split-sample technique) and then a final calibration using all available data should be accomplished (Rosbjerg and Madsen 2005). Simplification of the real systems, deficiency of the data, measurement errors, and uncertainty due to complex model designs are some of the important points during model predictions (Merdun 2006).

Computer-based mathematical modeling made attractive previously uninteresting empirical disciplines, which had low mathematical content and relied heavily on manual execution of various numerical and graphical techniques (Klemeš 2000). Disciplines, which until the 1950s covered the scope of today's agrometeorology were a prime example of such empirical subject fields. Numerical weather prediction was developing in the 1950s as one of the first computer applications (Gleick 1987), so the possibility of using numerical simulation to study climate became evident almost immediately. Climate modeling is one of the best examples of this trend. Its development is one of the great success stories of scientific simulation, independent of its presently still relatively meager successes.

Climate models have shown steady improvement over time as computer power has increased, our understanding of physical processes of climatic relevance has grown, datasets useful for model evaluation have been developed, and our computational algorithms have improved (Lorenz 2005). Nonetheless, our understanding of climate is still insufficient to justify proclaiming any one model "best" (Alexandrov et al. 2002; Bader et al. 2008; Kay and Davies 2008). Simulations from different state-of-the-science models have not fully converged, since different groups approach uncertain model aspects in distinctive ways. This absence of convergence is one useful measure of the state of climate simulation; convergence is to be expected once all climate-relevant processes are simulated in a convincing physically based way (Bader et al. 2008).

More appropriate in any assessments focusing on adaptation or mitigation strategies is to take into account, in a pertinently informed manner, the products of distinct models built, using different expert judgments at centers around the world. From many perspectives, an average over the set (ensemble) of models clearly provides climate simulation superior to any individual model, thus justifying the multimodel approach in many recent attribution and climate projection studies, such as in ensemble weather forecasting and ensemble climate prediction (Bader et al. 2008; Kay and Davies 2008).

The successes of climate modeling allow us to attempt to address many questions about climate by experimenting with simulations – that is, with mathematical models of the climate system (Bader et al. 2008). Despite the abundance of the climate modeling enterprise, the complexity of our Earth imposes important limitations on existing climate models. The typical example is the scale incongruity by interconnecting the climate models with crop models or hydrological models (e.g. Zhang 2005).

The effects of weather and climate on crops are complex. Despite the fact that many details of weather interactions with plant physiology are poorly understood, numerous realistic crop growth simulation models have been developed. There are several that have a high degree of sophistication and significant basic data requirements. Among them, the family of CERES crop models (e.g. in Eitzinger et al. 2004), the ApSim models (McCown et al. 1996), and CropSyst (Stockle and Nelson 1994), provide simulation tools that predict potential production, and also water limited production as well as nitrogen limited production. The use of these models is limited by the considerable information needed on crop, soil and environmental characteristics. Such information is seldom available, and the knowledge required to provide realistic estimates of the many (also still often empirical) parameters needed to run the models is quite substantial (Steduto et al. 2006).

An alternative to the models listed above can be a simpler, mechanistic model like AquaCrop (Doorenbos and Kassam 1979) that focuses on water limited crop production to provide predictions of attainable yields for a given water supply. Given the supply of water via rainfall and/or irrigation, a water balance is computed to arrive at the amount of water available for evapotranspiration. An estimate of direct losses in evaporation from soil is needed to arrive at an estimate of crop transpiration. With the recently obtained data from microlysimetry, this is rather well possible, although these values are much higher than originally expected (e.g. Kinama et al. 2005). Once transpiration is determined, the aboveground biomass is calculated using the user input biomass water productivity parameter. This latter parameter, provided experimentally, is normalized for climate so that it can be extrapolated to other climatic zones. The computed biomass is converted to yield by calculating the harvest index (Steduto et al. 2006). The dynamic simulation of all of these processes with a daily time step requires some basic data on crops, soils, and evaporative demand to run the model. One option is to provide default values in cases where all of the required data will not be available, but there are obvious limitations of this approach due to screen site-specific or region-specific environmental features. The biomass produced at the end of the season is an estimate of the attainable production for the amount of water available for transpiration. To calculate crop yield, an estimate of the harvest index is needed and is obtained as a fraction of the biomass produced. Some problems met are in Box IV.22.

Box IV.22

Current-generation crop models typically step through the growth process with daily frequency and use a number of meteorological variables as input, typically maximum and minimum temperature, precipitation, solar radiation, and potential evapotranspiration. A key characteristic of these models is that they have been developed for application at a single location and have been validated based on point data, including meteorological inputs (Eitzinger et al. 2004; Bader et al. 2008). Thus, their use in assessing climate change impacts on crop yields confronts a mismatch between the spatially averaged climate model grid box data and the point data expected by crop models. Downscaling of climate model grid box outputs is required because of the limitations of coarse spatial resolution in the global models. In mountainous terrain for example, a set of model values for a single grid box will represent conditions at the mean elevation level of that grid box. A prominent example is precipitation. The occurrence of heavy downpours is an important climate feature for certain impacts, but these events are often localized on a scale smaller than a grid box. In many actual situations, an area the size of a grid box may experience flooding rains at some points while others receive no rain at all. As a result, grid box precipitation tends to be more frequent, and the largest values typically are smaller than those observed at the local scale (Bader et al. 2008).

An example of today's farthest reaching approaches is that Zhang (2005) used statistical downscaling to estimate impact of climate change on water resources, soil erosion, and crop production (wheat yields) for a simulation of the future from HadCM3 (Hadley centre's Climate Model, UK) in Oklahoma. Univariate transfer functions were derived by calibrating probability distributions of GCM-projected monthly precipitation and temperature to match those of local climatology for the 1950–1999 period. Derived functions, which were tested for 1900–1949, were used to spatially downscale the HadCM3 monthly projections of 2070–2099 to the target station. Downscaled monthly data were further disaggregated to daily weather series using a stochastic weather generator for driving the prediction model.

Zhang's approach is logical and consistent and it produces different variability characteristics depending on whether future climate is wetter or drier than the present, unlike the simple delta method applied to daily climate data. However, these changes are assumed to be similar to what occurs in the present-day climate between wet and dry periods. So climate change itself degenerates some of the assumptions (Stigter 2008). Also more subtle climate model simulated changes that might affect yields (for example a change to longer wet and dry spells without a change in total precipitation) are not transmitted. Moreover, biases in climate model data can have unknown effects on crop model results, because the dependence of crop yields on meteorological variables is highly nonlinear (Bader et al. 2008).

The production of such scenarios deep into the future therefore remains a doubtful exercise. Already the irregularly distributed, uncoordinated, and in their total uncontrollable and unpredictable, millions of random elements of human civilization are seen to lead to frightening deterministic global changes in the short term.

It is up to the geophysicists, biophysicists and other natural and earth as well as "gamma" scientists to identify, interpret and predict these changes. Without their knowledge, without significant advances in, and convergence of, their respective sciences, mankind will find itself in the dark, maybe heading for its own destruction through a diligent pursuit of the millions of its everyday "urgent needs and benefits" (Klemeš 2000). In Chap. IV.3, Sivertsen and Gallis tried to show where and how alternatives could come in.

References

Addiscott TM, Wagenet RJ (1985) Concepts of solute leaching in soils: a review of modeling approaches. J Soil Sci 36:411–424

Alexandrov V, Eitzinger J, Cajic V, Oberforster M (2002) Potential impact of climate change on selected agricultural crops in north-eastern Austria. Glob Change Biol 8: 372–389

Anonymous (2001) Conceptual models of flow and transport in the fractured vadose zone. National Academy Press, Washington, 392pp

Bader DC, Covey C, Gutowski WJ, Held IM, Kunkel KE, Miller RL, Tokmakian RT, Zhang MH (2008) Climate models. An assessment of strengths and limitations. Synthesis and Assessment Product 3.1. Report by the CCSP and the SGCR, US Department of Energy, Office of Biological and Environmental research, Washington, 124pp

Doorenbos J, Kassam AH (1979) Yield response to water. Irrigation and Drainage Paper 33. FAO, Rome, Italy, 193pp

Eitzinger J, Trnka M, Hösch J, Žalud Z, Dubrovský M (2004) Comparison of CERES, WOFOST and SWAP models in simulating soil water content during the growing season under different soil conditions. Ecol Model 171:223–246

Gleick J (1987) Chaos: making a new science. Ando Publishing, Brno, Czech Republic, 349pp (in Czech)

Kay AL, Davies HN (2008) Calculating potential evaporation from climate model data: a source of uncertainty for hydrological climate change impacts. J Hydrol 358:221–239

Kinama JM, Stigter CJ, Ong CK, Ng'ang'a JK, Gichuki FN (2005) Evaporation from soils below sparse crops in contour hedgerow agroforestry in semi-arid Kenya. Agric For Meteorol 130:149–162

Klemeš V (2000) Common sense and other heresies. In: Sellars CD (ed) Selected papers on hydrology and water resources engineering. Canadian Water Resources Association, Cambridge, Canada, 378pp

Kňava K, Novák V, Orfánus T, Majerèák J (2008) High Tatras forest structure changes and their influence on rain interception and some components of water balance. Contr Geoph Geod 38:293–304

Lorenz EN (2005) Designing chaotic models. J Atmos Sci 62:1574–1587

McCown RL, Hammer GL, Hargreaves JNG, Holzworth DP, Freebairn DF (1996) APSIM: a novel software system for model development, model testing and simulation in agricultural systems research. Agric Syst 50:255–271

Merdun H (2006) Modelling approaches for flow and transport in unsaturated porous medium. International Symposium on Water and Land Management for Sustainable Irrigated Agriculture. Proceedings edited and published by Cukurova University, Adana, Turkey, no cons page

Rosbjerg D, Madsen H (2005) Concepts of hydrologic modeling. In: Anderson MG (ed) Encyclopedia of Hydrological Sciences. Wiley, Chichester, pp 155–163

Solomatine DP (2005) Data-driven modeling and computational intelligence methods in hydrology. In: Anderson MG (ed) Encyclopedia of hydrological sciences. Wiley, Chichester, pp 293–306

Steduto P, Fereres E, Hsiao TC, Raes D (2006) “Yield Response to Water”: The FAO revision framework and the crop-water productivity model *AquaCrop*. International Symposium on Water and Land Management for Sustainable Irrigated Agriculture. Proceedings edited and published by Cukurova University, Adana, Turkey, no cons page

Stigter CJ (1994) Micrometeorology. Ch. 5 In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 59–72

Stigter K (2008) Agrometeorological services under a changing climate: old wine in new bags. WMO Bull 57(2):114–117

Stockle CO, Nelson RL (1994) *Cropsyst* user’s manual (Version 1.0). Biological Systems Engineering Department, Washington State University, Pullman, WA, 235pp

Welles JF (1984) The survival advantage of stupidity. Spec Sci Technol 7:17–21

Zhang XC (2005) Spatial downscaling of global climate model output for site-specific assessment of crop production and soil erosion. Agric For Meteorol 135:215–229

IV.18 Monitoring and Early Warning

Andries Rosema, Marjolein De Weirdt, and Steven Foppes

Knowledge of the relation between climate and plant growth has advanced considerably, but applications are hampered by lack of data. Measuring stations are too widely spaced and their data represent only samples from highly variable meteorological data fields. They often do not meet the practical needs at a given time and place.

Geostationary meteorological satellites may provide a solution to this problem. Although their spatial resolution is quite low (3–5 km), their observations cover the world every hour, sufficient to cover precipitation events and to monitor the earth surface "through" the clouds. Since the early 1980s we have been working on the development of the Energy and Water Balance Monitoring System (EWBMS) (Rosema 1990, 1993; Rosema et al. 1998a; Roebeling et al. 2004; De Weirdt et al. 2007), which today is fully operational over Europe, Africa and Asia and delivers a continuous stream of surface temperature, air temperature, global and net radiation, actual and potential evapotranspiration as well as rainfall distribution data.

Actual Evapotranspiration represents a new and very significant information source. It is the key to applications related to the water budget of river catchments, agricultural drought, crop growth and the carbon cycle. Its relevance to crop growth and the carbon cycle is based on the well-established proportionality between evapotranspiration and CO_2 assimilation (Stewart et al. 1977; Doorenbos and Kassam 1979).

An overview of the EWBMS is shown in Fig. IV.28. The satellite data are first pre-processed, which includes such tasks as calibration and atmospheric correction (not shown). Then there are two processing lines, one to generate rainfall data fields using satellite information on the presence and duration of cloud tops at different heights. The rainfall processing requires external rain gauge data obtained in near real time from the WMO GTS system. The energy balance processing line generates from surface temperature, surface albedo and cloud information the components of

A. Rosema (✉)
EARS B.V., Delft, The Netherlands
e-mail: andries.rosema@ears.nl

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_118,

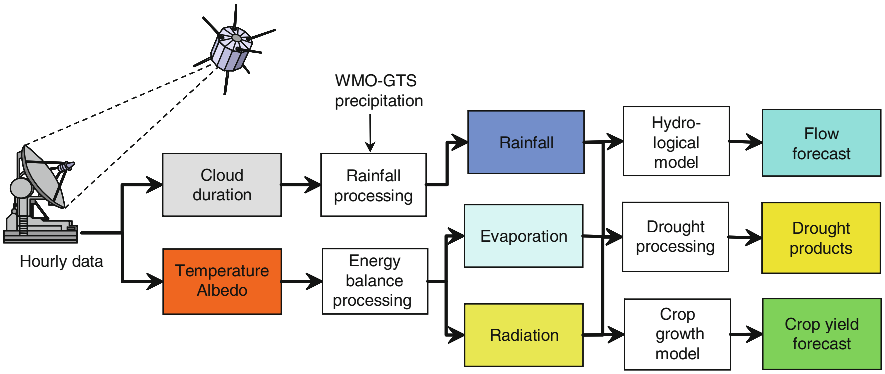


Fig. IV.28 Overview of the energy and water balance monitoring system

the radiation and energy balance: global radiation and net radiation, sensible heat flux, actual and potential evapotranspiration. This processing requires no external data!

The basic data products that are derived and used for further application processing consist of temperature, rainfall, actual evapotranspiration and radiation. Three types of application have been developed. The river flow forecasting applications will not be further discussed here, but since the beginning of 2009 they are operational in the Yellow River (China). Here we will particularly discuss the agricultural drought and crop growth applications.

Actual evapotranspiration depends on water availability in the root zone of the plant canopy and on radiation. By dividing the actual evapotranspiration through the potential evapotranspiration, which is mainly governed by radiation, the resulting relative evapotranspiration (RE) depends predominantly on soil moisture availability to the plant canopy and is therefore a very suitable agricultural drought indicator.

From theory the relative evapotranspiration depends on the soil moisture tension in the root zone, but empirically one can observe a good relation with plant available water in the soil. This is discussed here, whereas soil moisture content has always been the standard information collected, but in principle the relative evapotranspiration is a much more attractive agricultural drought indicator, as it is directly related to CO_2 assimilation and crop production.

As an agricultural drought indicator we propose and use the Evapotranspiration Drought Index (EDI), which is given by EDI $= \mathrm{A}E^{2\mathrm{m}}/E_{\mathrm{P}}{}^{2\mathrm{m}}$, i.e. the 2-monthly RE (Fig. IV.29). Operationally the EDI is generated as a moving average. The 2 months time frame can be selected such that the EDI value represents the critical phases of crop growth and may be used then directly as a first estimator of expected crop losses.

The RE is a very important quantity as it is closely related to CO_2 assimilation. Plants exchange both water vapour and CO_2 through their stomata. In case of water shortage the stomata are closed to stop water loss and to maintain structural integrity.

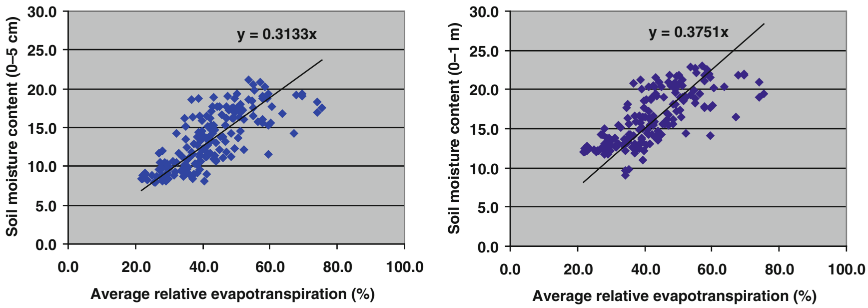


Fig. IV.29 Empirical relation between satellite derived 2-monthly RE and soil moisture content in the top 5 cm (*left*) and top 1 m of soil (*right*). Volumetric soil moisture is about 1/3 of RE (both in %)

As a consequence also CO_2 uptake is reduced. It can be shown theoretically and it has been shown empirically that as a result of stomatal closure H_2O and CO_2 fluxes are reduced proportionally and that the precise relation depends on the mesophyll resistance (Slabbers et al. 1979). Stewart et al. (1977) were probably the first to make practical use of this fact, proposing the relation

$$1 - \mathrm{RG} = k_{\mathrm{y}}(1 - \mathrm{RE}) \tag{1}$$

where RG is the relative growth, with k_{y} a constant characterizing the drought resistance of a crop.

Doorenbos and Kassam (1979) extensively documented the relation for different crops and different parts of the growing season. In the past, however, RE always had to be assessed indirectly on the basis of scarce rainfall data and applying a soil water budget model. This, for example, is how the FAO Water Requirement Satisfaction Index works (Gommes 1983; Frère and Popov 1986). But using the EWBMS satellite monitoring technique, it is not necessary anymore to collect scarce and often non-representative rain gauge data, as the actual evapotranspiration is directly measured from the satellite energy balance data for any location. This also implies that crop growth models can be very much simplified, as they do not need a soil compartment and the related input data on soil type and depth, which information is usually not accurately known.

An appropriate growth model is used in combination with the data from the EWBMS. It starts from Monteith's (1977) observation that biomass production can be explained from light interception, and in this respect is almost the same for different species. This insight has been the basis for remote sensing products that present the "absorbed photosynthetic active radiation". But these are not very useful as they are far from real production. They omit two important elements, which did play a role in Monteith's work in the UK: light saturation and water limitation. We have included these elements in the EARS Crop Growth Model (ECGM). In this model the daily biomass production is given by:

$$\partial B/\partial t = f_c\, f_g.C.\text{RG}.\phi.\underline{a}.\text{PAR} - R(\text{gm}^{-2}\text{day}^{-1}) \tag{2}$$

where B is the biomass, t is the time in days, f_c is the conversion factor from photons to glucose (4 g gmole^{-1}), f_g is the growth respiration factor (~0.75), C is the light interception factor, RG again the relative growth, resulting from water limitation, ϕ is the average daily light use efficiency, $\underline{a}$ is the PAR absorption coefficient (~0.8), PAR the photosynthetic active radiation (gmole m^{-2}day^{-1}) and R the maintenance respiration. The light interception factor C is usually modelled as the ratio between the biomass and the biomass at crop closure ($C = B/B_c$). The photosynthesis light use efficiency may be estimated with the following relation (Rosema et al. 1998b; Roebeling et al. 2004):

$$\phi = (d/12)^{0.5}/(1.25 + 2.r_e.\text{PAR}) \tag{3}$$

where d is the daylength in hours, and r_e an effective plant electron transport resistance. The daily biomass loss due to R is about 2% per day. It may be calculated in dependence of temperature using one of the appropriate relations published in the literature. RG in (2) is determined with the Stewart relation (1) from the EWBMS relative evapotranspiration data.

Given the EWBMS temperature, radiation and evapotranspiration fields from the satellite we may estimate for each pixel the biomass increase, starting from an initial biomass at germination. By summing up the biomass growth day by day we can simulate the crop development through the growing season. The most important crop specific parameter in this process is k_y in (1), which characterizes the drought resistance of a crop. Values of k_y may be found in Doorenbos and Kassam (1979). For example millet and sorghum are drought resistant and have $k_y = 0.9$ and maize is drought sensitive with $k_y = 1.25$.

An example of the biomass development during the growing season, modelled for different values of the relative evapotranspiration (for this theoretical example taken constant through the growing season) is presented in Fig. IV.30. Note that after 70 growing days the ratio between "actual" biomass and "potential" biomass, called the relative biomass, becomes nearly constant. This observation is the basis of our crop yield forecasting approach.

Crop growth models are usually not very accurate. The simple model discussed in the previous section is a simplification of reality. The more complex and detailed models however suffer from high input requirements on soil, crop and cultivating practice, which is usually not available. Given this consideration we use the model generated biomass data in a relative way. We first generate relative yield data fields:

$$\text{RY} = Y/Y_P \approx \text{RB} = B/B_P \tag{4}$$

where RY is the relative yield, assumed to be approximately equal to the relative biomass RB. B_P is the biomass that is obtained with the model if there is no water limitation (RE = 1). RY and RB vary considerably in the beginning of the growing

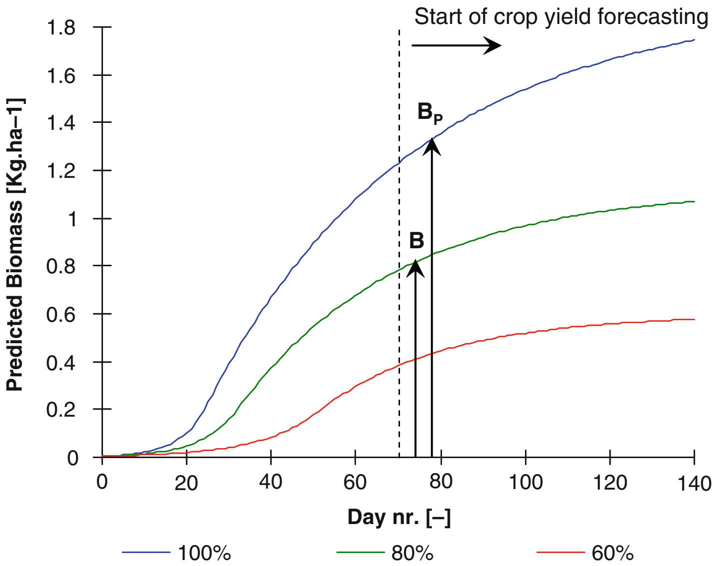


Fig. IV.30 Biomass simulations at different levels of relative evapotranspiration

season. However, halfway the growing season, after about 70 growing days, RY and RB become more stable and almost constant (Fig. IV.30).

Therefore the relative yield after 70 growing days can be considered a forecast of the relative yield at harvest. From this relative yield the forecasted absolute yield (Y) could be determined if the potential crop yield (Y_P) is known, which is usually not the case. For this reason also the satellite data of the previous five years are processed to generate the satellite derived relative yields of the previous 5 year and their average RY^a as well. Then we define the difference yield as:

$$DY = (RY - RY^a)/RY^a \tag{5}$$

Because the potential yield is about constant, this reduces to

$$DY = (Y - Y^a)/Y^a \tag{6}$$

RY and DY are both data products of the satellite monitoring system. Equation (6) can be used to forecast the current season crop yield as

$$Y = Y^a(1 + DY) \tag{7}$$

where Y is the forecasted crop yield, Y^a the reported average yield of the same crop in the same area in the previous 5 year, and DY the difference yield derived with the EWBMS-ECGM system from the satellite data.

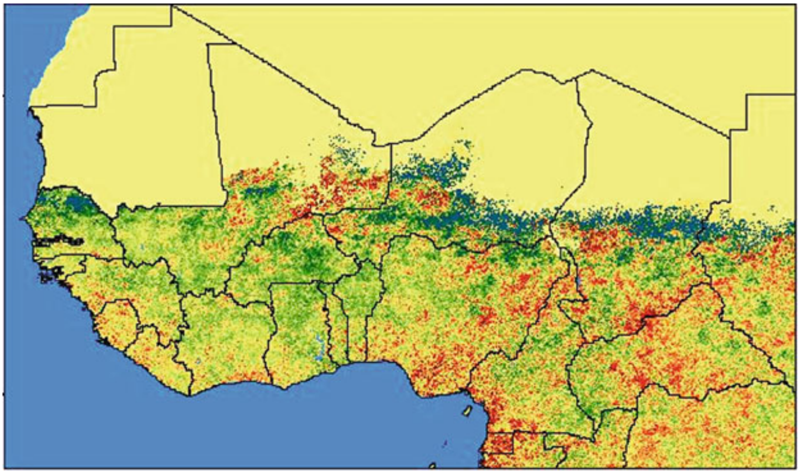


Fig. IV.31 Sorghum/millet difference yield (DY) forecast for West Africa, 11 September 2008

Figures IV.31 and IV.32 show examples of sorghum/millet and maize DY forecasts produced and issued through Reliefweb in 2007. First forecasts where generated at the end of July and then updated every 10 days incorporating the latest satellite data. The examples shown are from the end of the season and include the data from the beginning of the growing season till the first 10 days of September inclusive.

At EARS the satellite data processing and subsequent GIS steps proceed largely automatically and crop yield forecasts for each province and district in Africa or Europe can be generated within 1 or 2 days. During the summer of 2007 10-daily crop yield forecasts were published for West and East Africa on the UN humanitarian website Reliefweb (Figs. IV.31 and IV.32). Potato yield forecasts have been made for Europe and a coffee yield forecast was generated for Rwanda (see http://www.ears.nl).

The EWBMS system is a satellite based monitoring system that provides abundant climatic near real time information for every location of the hemisphere viewed. The system provides essential data related to water and food, such as temperature, radiation, evapotranspiration and rainfall, and in this respect fills the large gaps between existing measuring stations. Moreover, the data are objective, uniform and economic. Current operational applications of the system are crop yield forecasting (Africa and Europe), water resources monitoring and flow forecasting (Yellow river, not discussed), rangeland biomass forecasting and carrying capacity monitoring (Mongolia, not discussed). There is considerable scope and future for this and other such satellite based monitoring systems that provide abundant quantitative data that users are familiar to. They have clear advantage over the many satellite remote sensing products of which the meaning is not well known to end-users in this field.

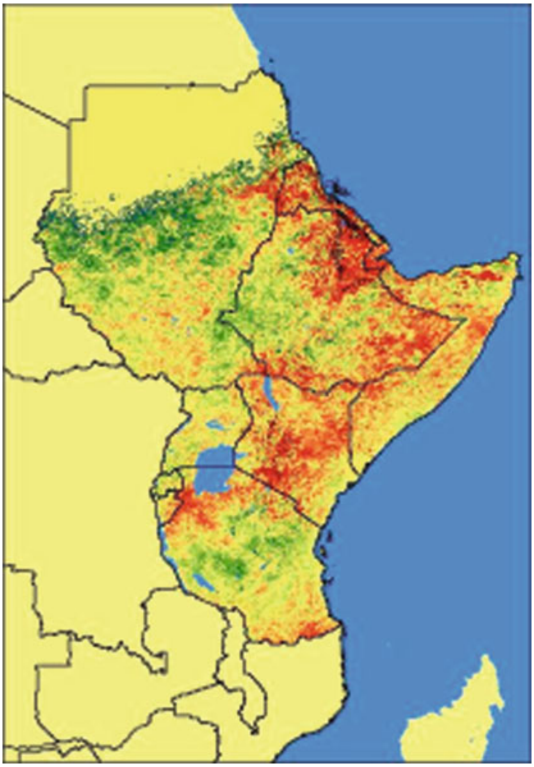


Fig. IV.32 Maize difference yield (DY) forecast for East Africa, 11 September 2008

References

DeWeirdt M, Rosema A, Zhao W, Foppes S, Wang C, Dai D (2007) Evapotranspiration monitoring and validation in the Wei River basin and upper Yellow River basin, Vol. I. Proceedings of the 3rd International Yellow River Forum, Dongying,, pp 120–128

Doorenbos J, Kassam AH (1979) Yield response to water. FAO Irrigation and Drainage Paper 33. FAO, Rome, 193pp

Frère M, Popov GF (1986) Early agrometeorological crop yield assessment. FAO Plant Production and Protection Paper 73. FAO, Rome, 124pp

Gommes R (1983) Pocket computers in agrometeorology. FAO Plant Production and Protection Paper 45. FAO, Rome, 140pp

Monteith JL (1977) Climate and efficiency of crop production in Britain. Philos Trans R Soc, Lond, B 281:277–294

Roebeling RA, Van Putten E, Genovese G, Rosema A (2004) Application of Meteosat derived meteorological information for crop yield predictions in Europe. Int J Remote Sens 25: 5389–5401

Rosema A (1990) Comparison of Meteosat based rainfall and evapotranspiration mapping in the Sahel region. Int J Remote Sens 11: 2299–2309

Rosema A (1993) Using Meteosat for operational evapotranspiration and biomass monitoring in the Sahel region. Remote Sens Environ 45:1–25

Rosema A, Roebeling R, Kashasha D (1998a) Using Meteosat for water budget monitoring and crop early warning. In: Rijks D, Terres JM, Vossen P (eds) Agrometeorological applications for regional crop monitoring and production assessment. Joint Research Centre, European Commission Publication EUR 17735 EN, pp 161–175

Rosema A, Snel JFH, Zahn H, Buurmeijer WF, Van Hove LWA (1998b) The relation between laser-induced chlorophyll fluorescence and photosynthesis. Remote Sens Environ 65:143–154

Slabbers PJ, Sorbello Herrendorf V, Stapper M (1979) Evaluation of simplified water-crop yield models. Agric Water Manag 2:95–129

Stewart JI, Hagan RM, Pruitt WO, Hanks RJ, Riley JP, Danielson RE, Franklin WT, Jackson EB (1977) Optimizing crop production through the control of water and salinity levels in the soil. Technical report PRWG 151-1, Utah Research Laboratory, Utah State University, Logan, no pages

IV.19 Remote Sensing

Andres C. Ravelo and Ernesto G. Abril

The benefits of a wealth of observational data, derived products and internal services from specially equipped and highly sophisticated environmental satellites have reached the meteorological sciences and associated environmental disciplines such as hydrology and oceanography. The same applies to agricultural meteorology (e.g. Milford 1994; Basso et al. 2010). There are two kinds of sensors used in remote sensing. Passive remote sensing sensors detect radiation that is emitted or reflected by the object or surrounding area being observed. Reflected sunlight is the most common source of radiation measured by passive sensors. Active sensors, on the other hand, emit energy in order to scan objects and areas and then detect and measure the radiation reflected or backscattered from the target using a passive sensor. Radar is an example of active remote sensing where the time delay between emission and return is measured and then the location, height, speed and direction of an object are established (Basso et al. 2010).

The following features are unique for environmental satellites (Conway 1997):

- High vantage point and broad field of view, providing a regular supply of useful data from those areas of the globe with very few or none conventional observations.
- Large scale environmental features can be seen in a single view.
- Continuous monitoring of a major portion of the atmosphere from space, making them particularly suited for early warning of short-lived meteorological phenomena.
- The onboard advanced communication systems permit rapid data transmission to operational users.

A.C. Ravelo (✉)
CREAN/Universidad Nacional de Córdoba – CONICET, Córdoba, Argentina
e-mail: ravelo@crean.agro.uncor.edu

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_119,

The design of meteorological satellites is geared to provide three major data sources (Kelkar 2007):

- Spectral radiation, which can be converted into estimates of cloud cover and cloud motion, land and sea surface temperatures and atmospheric variables such as temperature, humidity, ozone, etc.
- Data gathered from sensors based on remote platforms.
- Real time information on cloud cover images and other meteorological information broadcasted directly to users with a direct readout station.

A systematic effort in land use planning is an appropriate way to assure a sustainable agricultural development. Agroclimatic zoning is used to characterize geographic areas based on climate, soil, biology and production information. Remote sensing and geographic information systems have added a new dimension in integrating geospatial data.

There is for example a need to reduce the farmer's risk when foresting new lands. Both satellite and ground information are essential ingredients to develop advisory systems and planning strategies for forest farming investments. An agroclimatic zoning for pine plantation in the Calamuchita valley of Córdoba, Argentina was established using climate, soil and biological/productive variables for pine trees (Ravelo et al. 2001). The zoning was based on three major factors: temperature and radiation conditions, soil water balance and pine tree growth indices.

The available weather stations in the region with temperature records were used to calibrate satellite-derived temperature estimates using LANDSAT 7 Thematic Mapper images and a Digital Elevation Model (Eastman 2006). A soil moisture balance (Palmer 1965) provided insights into the available water regime for the region. Site quality for pine tree was established using growth curves for 30 sampling sites in the region. The agrometeorological conditions for the sampling sites were identified and their relationships with the pine tree growth indices were obtained. The relationships allowed the definition of several pine tree suitability categories for the sites.

The region was classified in these categories based on their agrometeorological characteristics. A map (Fig. IV.33) was created showing areas suitable and not suitable for pine growing. The suitable areas ranged from excellent to poor pine tree growing conditions. The map can be used as an agrometeorological service (see Parts I and II of this book) to make farming decisions on where pine planting will provide the best return for investment and as a reference to lower farmer risks.

Lack of rainfall or precipitation in amounts well below normal over an extended period of time will lead to the onset of a drought, affecting grain crops, pastures and forests. Drought is a regional event which can be monitored and assessed using ground information and remote sensing information (Ravelo and Pascale 1997). Satellite based indices such as the Normalized Difference Vegetation Index (NDVI, e.g. Milford 1994) and meteorological drought indices are widely used to monitor drought occurrence and drought intensity in both time and space (Ravelo et al.

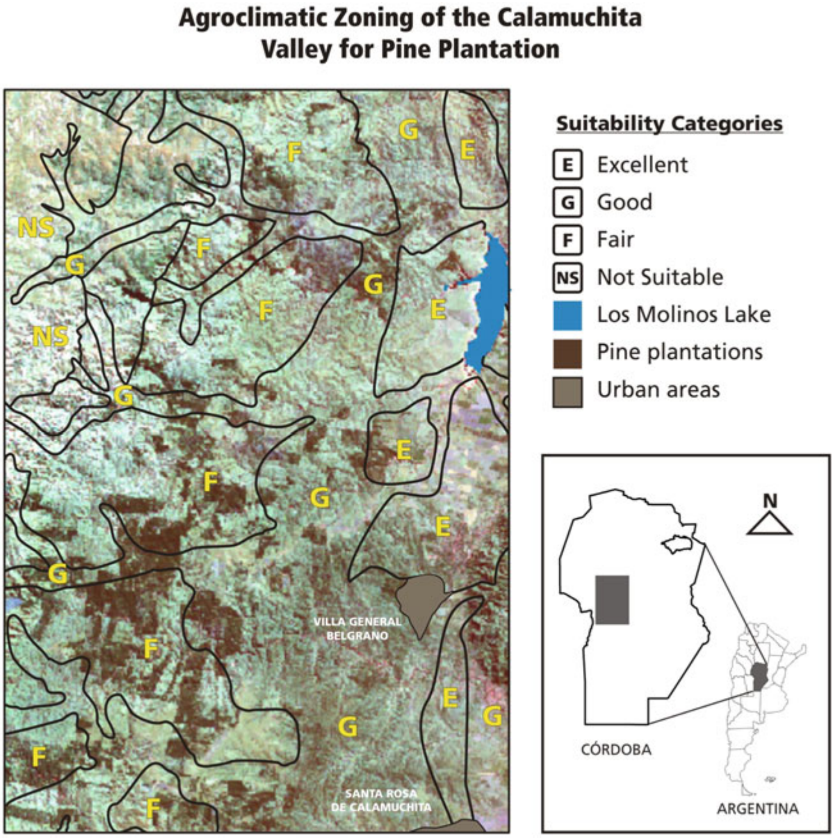


Fig. IV.33 Agroclimatic zoning of the Calamuchita valley (Argentina) for pine plantation using ground and satellite information

2008). This information can be used by the government for farmers to establish mitigation measures such as tax relief, no-interest loans, etc.

The comparison between actual NDVI with average NDVI can be used to identify areas with below average conditions which are closely related to drought occurrence. Figure IV.34 shows extensive drought impacted areas in Mexico during 1998 (Ravelo 2008). Crop damages and related severe water shortages for irrigation were caused by these extensive droughts. Consequently, farmer and government revenue losses reached millions of dollars, triggering the needs for an operational system for monitoring and assessment of drought as well as feedback mechanisms with the farmer community for drought impact relief (Ravelo 2008).

Remote sensing methods are becoming increasingly important for mapping land use and land cover, because, among other advantages, large areas can be imaged quickly and repetitively. They eliminate the problem of surface access. Remote sensing images particularly provide an objective, permanent dataset that may be interpreted for a wide range of specific land uses and land covers, such as in forestry

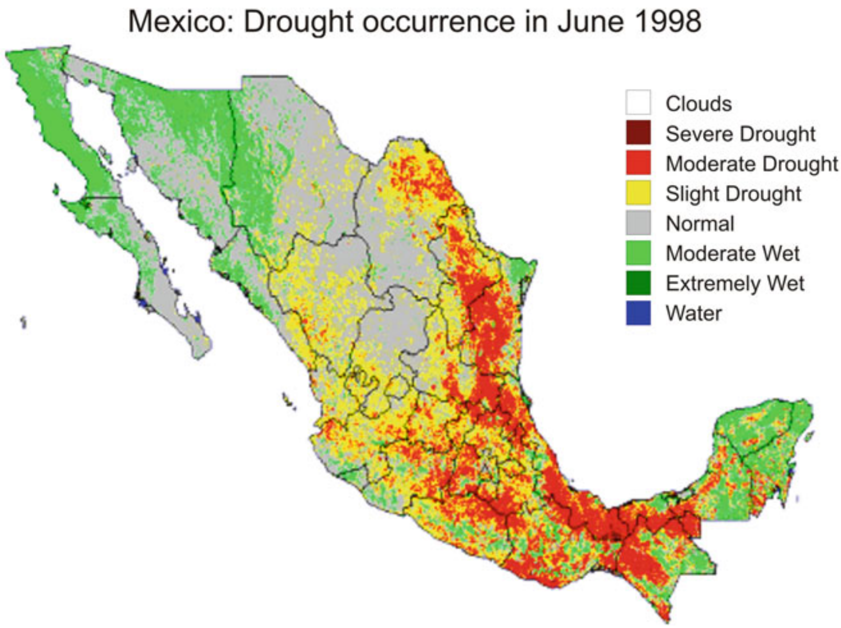


Fig. IV.34 Drought affected areas in Mexico during June 1998

and agriculture (e.g. Sabins 1997). The analysis process essentially involves the transformation of remotely sensed measures of spectral radiance into information about the composition of the land surface.

Using different techniques, a land use classification was carried out in Central Argentina (Fig. IV.35), to estimate the area sown with wheat (not shown), maize and soybean crops (Grilli et al. 2006). Five hundred training sites were assessed for maize crop area and soybean crop area estimation and 97 for wheat crop area estimation while six Landsat 5 Thematic Mapper scenes were used to estimate the land cover of the study area.

Two classifications approaches were employed: for wheat estimation the Linear Discriminant Analysis (Fisher Classifier with 97% accuracy) and for maize and soybean estimation the Minimum Distance to Means (Mindist, Fig. IV.35) classifier with 73% accuracy assessment (Sabins 1997, Eastman 2006).

Doraiswamy and Stern (2007) were classifying corn and soybean crops in the US corn belt with an accuracy between 75 and 83%, using the NDVI time series profile and different threshold values (0.4 at the beginning and end of the crop season and 0.8 at mid-season).

In Brazil, Doraiswamy et al. (2006) used the Moderate Resolution Imaging Spectroradiometer (MODIS) on-board the Terra satellite for assessing soybean crop area.

During the lifetime of a crop, a number of growth or phenological stages can be identified, each of them with specific bioclimatic requirements. Therefore, crop

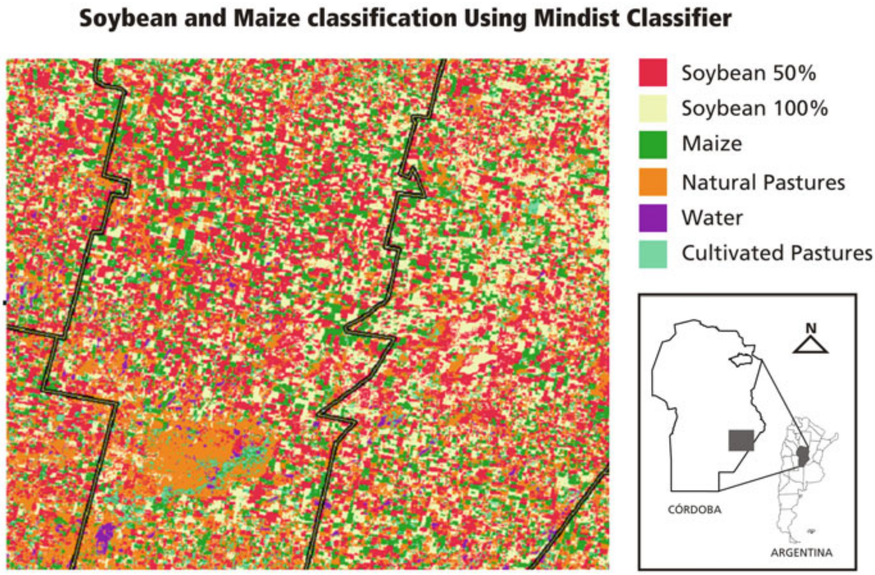


Fig. IV.35 Classification of soybean and maize crops in Cordoba, Argentina

phenology refers to the initiation, differentiation, and development of organs which are referred to as phenostages. It involves qualitative evolution in form, structure and general state of the complexity of the plant.

Information on crop phenology is essential for crop management, where timing of management practices is increasingly based on stages of crop development. In addition, crop phenology information is needed for evaluating crop productivity. Crop phenology can be evaluated with time series of satellite images for dates at which specific growth curve features appear and they can be associated to phenostages.

A method for determining phenological stages of paddy rice in Japan using remote sensing information was developed by Sakamoto et al. (2005). The method uses multi-temporal MODIS/Terra data; time-series of Enhanced Vegetation Index (EVI) and phenological stages detected from the smoothed EVI time profile (planting date, heading date, harvesting date, and growing period). Some applications of identified crop phenological stages are found in crop yield models, assessing deviations in crop calendar, forecasting the development of climate driven diseases and supporting long term analysis in terms of land cover change.

Early assessment of crop production can benefit strategic planning of both producers and consumers of agricultural goods and is appreciated for the same reasons by relevant government departments. Timely and accurate crop yield forecasting on regional and national scales is increasingly becoming relevant across grain producing countries at both subsistence and commercial levels. For subsistence agriculture, Thornton et al. (1997) used satellite and ground-based data for crop simulation modeling in Burkina Faso to estimate millet production for Famine Early Warning Systems. Validated model outputs can allow policy makers to take appropriate steps to reduce the negative impacts of food shortages on vulnerable urban and rural populations.

In commercial agriculture, soybean and maize crops are monitored for grain production assessments in central Argentina (Ravelo et al. 2006). This includes to record relevant weather and crop variables related to crop productivity and to operate crop yield models for estimating soybean and corn yields at both plot and regional levels. Satellite data included Spot-Vegetation imagery (1 km resolution, 10-day composite) and Aqua imagery (250 m resolution, 16-day composite).

Weather information was obtained from nearby ground stations. Crop status and yield forecast are issued routinely. Grain consuming countries are interested in knowing the levels of grain production entering the commercial markets and their impacts on grain prices (Genovese et al. 2001; Lewis et al. 1998). Several methods have been investigated which are based on validated, objective techniques such as crop growth modeling and remote sensing (Atzberger et al. 2001; Doraiswamy et al. 2007; Rojas 2007).

In many countries, advances in farm management are possible by using real time satellite data. For example, precision agriculture is associated to remote sensing technology, basically through the use of global positioning systems (GPS) (Grisso et al. 2003). The efficient use of fertilizers, soil conditioners, pesticides etc. is carried out by machinery with precise equipment using GPS information (Pfost et al. 1998). Soil properties of plot samples are linked to geographic coordinates of each sample.

This information allows the development of a map showing the geographic distribution of soil properties, nutrient deficiencies, pH levels, organic matter contents, etc. The map is used to calibrate the machinery in applying regulated amounts of fertilizer, soil conditioners, etc. Han et al. (1995) developed an interface between a geographic information system and a simulation model to study potato yield and nitrogen leaching distribution for site-specific crop management in precision farming in a 50 ha field.

An increased transfer of operational satellite data takes place to those developing countries that are able to absorb and use them and new methodologies for processing and interpreting satellite images become available. A review has been given in Table IV.5 in Box IV.23. The continuing decrease in costs for receiving equipment, data storage and processing hardware points to a positive future for remote sensing applications in farming activities of the more well off farmers and in government overseen and serviced agriculture. There are ready available long series of satellite data (NOAA/AVHRR, Meteor and Spot-Vegetation) for research and operational work. The access and transfer of satellite data has become easier where communication systems such as internet, file transfer protocols, etc. are available (Schmidt et al. 2006).

Box IV.23

The development of space technology has led to a substantial increase in satellite earth observation systems. Today, artificial satellites influence many aspects of human activities, providing scientists and educators with tools for investigation, inquiry, analysis and stewardship. There are two main types of environmental satellites, defined by their orbital characteristics: Polar Operational Environmental Satellites (POES) and Geostationary Operational Environmental Satellites (GOES) (Conway 1997). In the short span of 4 decades, several thousands of satellites were launched and according to NASA, there are currently over 2,500 satellites orbiting earth (Stoney 1997). Table IV.5 shows operational satellites and some of the applications in natural resources and agriculture for developing countries. In addition, an enhanced information and communication technology has effectively increased the processing of data and their distribution over the internet system. However, in many places of the developing world, particularly in Africa and the remoter areas of Asia and South America, internet connectivity leaves much to be desired (e.g. Van Rossom 2009).

Table IV.5 Operational satellites and applications in developing countries

Operational Satellites	Applications	Examples of Applications in Developing Countries
SPOT	• Land cover/use classification	– Land use systems in Senegal (FAO 2007)
	• Vegetation and hydrological conditions analysis	– Multi-captor remote sensing for an integrated vegetation – hydrological model: preliminary results (Zin et al. 2003)
	• Agricultural and natural resources management	– Joint learning with GIS: multi-actor resource management (Gonzalez 2002)
NOAA/ AVHRR	• Vegetation and hydrological conditions analysis	– Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981–2003 (Anyamba and Tucker 2005) – Seasonal and interannual analysis of wetlands in South America using NOAA-AVHRR NDVI time series: the case of the Parana Delta region (Zoffoli et al. 2008)
	• Crop yield estimates	– Using satellite and field data with crop growth modeling to monitor and estimate corn yield in Mexico (Báez-González et al. 2002) – Monitoring Brazilian soybean production using NOAA/AVHRR based vegetation condition indices (Liu and Kogan 2002)
TERRA-ACQUA/ MODIS Sensor	• Vegetation and hydrological conditions analysis	– Climate and human impacts on water resources in Africa (Coe et al. 2002)

Table IV.5 (continued)

Operational Satellites	Applications	Examples of Applications in Developing Countries
	• Land cover/use classification	– Aperfeiçoamento do monitoramento do uso e cobertura do solo com dados MODIS a partir da utilização de um diagrama de transição de estados (Enhanced monitoring of land use and land cover using MODIS data with a transition scheme) (Jonathan et al. 2007)
LANDSAT 5 and 7 TM	• Vegetation and hydrological conditions analysis	– Analysis of Vegetation Changes in High Andean Wetlands Using Remote Sensing as a Contribution to Environmental Planning in Southern Peru (Otto and Richters 2007) – Hybrid classification of Landsat data and GIS for land use/cover change analysis of the Bindura district, Zimbabwe (Kamusoko and Aniya 2009)
	• Land cover/use classification	– Investigation of the land use/land cover change in the Upper-Oue'me' catchment Benin (West-Africa) for the set up of a coherent development plan (Thamm et al. 2001)
	• Agricultural and natural resources management	– Integration of RS, GIS and AHP for Hanoi peri-urban agriculture planning. (Map Asia 2004) (Thapa et al. 2004)
ERS-1 SAR	• Digital elevation model	– Modelling topography with SAR interferometry: illustrations of a favourable and less favourable environment (Kervyn 2001)
	• Flood monitoring	– Flood and coastal zone monitoring in Bangladesh with Radarsat ScanSAR: Technical experience and institutional challenges (Werle 2000) – Mapping of flood dynamics and spatial distribution of vegetation in the Amazon floodplain using multi temporal SAR data (Martínez and Toan 2007)

There is a need for data compatibility, integration between different sources of data, standardization of procedures and routine analysis. These two latter issues require capacity building in developing countries there where new needs arise from the agricultural community. Training on specific applications of remote sensing data for both producers and users of those applications will in these cases assure benefits from the satellite system utilization. There are a number of projects geared to provide data, software, hardware and training to developing countries. For example, the GEONETCast for and by Developing Countries project (DevCoCast as the acronym) (VITO 2008) has the following objectives:

1. Disseminate existing environmental added-value datasets (both in-situ and satellite based) from various sources in Africa, South- and Central America and Europe in (near) real time and at no cost via GEONETCast to a broad range of user communities in developing countries.
2. Support the use of those products.

By utilizing the existing EUMETCast dissemination system (Fig. IV.36), benefits may be expected from the operational technical infrastructures once there is a well developed user base in Africa and South-America. This may enable to focus the efforts on supporting the data use and building up the capacity in developing countries, which includes training, workshops, networking and outreach.

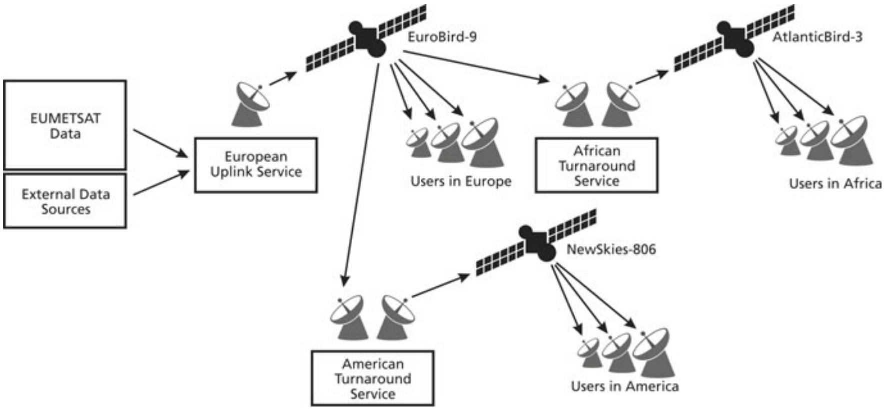


Fig. IV.36 EUMETCast system overview of the data flow

As earlier dealt with in this book, there remains an actual danger that these applications are technology driven and not need driven. The agrometeorological community has to serve the actual needs of farmers, with an up to date knowledge of those needs, in agrometeorological services and advisories. The present limitations have recently again been spelled out (Singh et al. 2008).

References

Anyamba A, Tucker CJ (2005) Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981–2003. J Arid Environ 63:596–614

Atzberger C, Guerif M, Delecolle R (2001) The use of GRAMI crop growth model and SPOT data for biomass estimations in winter wheat. INIST-CNRS, Cote INIST:Y 33730 Aussois, 25pp

Báez-González AD, Chen Pei-yu, Tiscareño-López M, Srinivasan R (2002) Using satellite and field data with crop growth modeling to monitor and estimate corn yield in Mexico. Crop Sci 42:1943–1949

Basso B, McVicar TR, Lee B, Yazdanpanah H, Das HP (2010) Remote sensing and GIS applications in agrometeorology. Chapter 4 In: Guide to agricultural meteorological practices, 3rd edn.

WMO 134, Geneva. [Available on WMO (www.wmo.int/pages/prog/wcp/agm/agmp_en.html) and INSAM (www.agrometeorology.org) websites.]
Coe MT, Ramankutty N, Birkett Ch (2002) Climate and human impacts on water resources in Africa. http://lcluc.umd.edu/Documents/results-3-2002.asp
Conway ED (1997) An introduction to satellite image interpretation. The Johns Hopkins University Press, Baltimore, 264pp
Doraiswamy PC, Stern AJ (2007) Crop classification in the U.S. Corn Belt using MODIS imagery. Proceedings of the International Geoscience and Remote Sensing Symposium, Barcelona, pp 809–812
Doraiswamy PC, Akhmedov B, Stern AJ (2006) Improved techniques for crop classification using MODIS imagery. Proceedings of the International Geoscience and Remote Sensing Symposium, Denver, pp 2084–2087
Doraiswamy PC, Akhmedov B, Beard L, Stern A, Mueller R (2007) Operational prediction of crop yields using MODIS data and products. Workshop Proceedings: Remote Sensing Support to Crop Yield Forecast and Area Estimates. ISPRS Archives XXXVI-8/W48
Eastman RJ (2006) IDRISI Andes guide to GIS and image processing – Clark Labs, Clark University, Atlanta, 328pp
FAO (2007) Land use system and soil degradation in Senegal. LADA Project. www.fao.org/lada
Genovese G, Vignolles C, Nègre T, Passera G (2001) A methodology for a combined use of Normalised Difference Vegetation Index and CORINE land cover data for crop yield monitoring and forecasting. A case study on Spain. Agronomie 21:91–111
Gonzalez RM (2002) Joint learning with GIS: multi-actor resource management. Agric Syst 73(1):99–111
Grilli MP, Ravelo AC, Santa AJ, Zanvettor RE (2006) Estimation of the cultivated areas of soybean, maize and wheat using remote sensing techniques. Proceedings of the 2nd International Workshop on Crop Monitoring and Forecasting in South America. Montevideo, 9–11 October, JRC/EU-FAO. CDROM
Grisso R, Oderwald R, Alley M, Heatwole C (2003) Precision farming tools: global positioning system (GPS). Virgina Coop. Extension, Virgina State University Publication Number: 442–503. http://www.ext.vt.edu/pubs/bse/442-503/442-503.html
Han S, Evans RG, Hodges T, Rawlins SL (1995) Linking geographic information system with a potato simulation model for site-specific crop management. J Environ Qual 24:772–777
Jonathan M, Simões Penello Meirelles M, da Costa Coutinho HL, Berroir JP, Herlin I (2007) Aperfeiçoamento do monitoramento do uso e cobertura do solo com dados MODIS a partir da utilização de um diagrama de transição de estados. [Enhanced monitoring of land use and land cover using MODIS data with a transition scheme] Anais XIII Simpósio Brasileiro de Sensoriamento Remoto, Florianópolis, Brasil, 21–26 April, INPE, pp 5839–5845
Kamusoko C, Aniya M (2009) Hybrid classification of Landsat data and GIS for land use/cover change analysis of the Bindura district, Zimbabwe. Int J Remote Sens 30:97–115
Kelkar RR (2007) Satellite meteorology. BS Publisher, Andhra Pradesh, 252pp
Kervyn F (2001) Modelling topography with SAR interferometry: illustrations of a favourable and less favourable environment. Comput Geosci 27:1039–1050
Lewis JE, Rowland J, Nadeau A (1998) Estimating maize production in Kenya using NDVI: some statistical considerations. Int J Remote Sens 19:2609–2617
Liu WT, Kogan F (2002) Monitoring Brazilian soybean production using NOAA/AVHRR based vegetation condition indices. Int J Remote Sens 23:1161–1179
Martínez JM, Le Toan T (2007) Mapping of flood dynamics and spatial distribution of vegetation in the Amazon floodplain using multitemporal SAR data. Remote Sens Environ 108:209–223
Milford JR (1994) Remote sensing for agricultural meteorology. In: Griffiths JF (ed) Handbook of agricultural meteorology. Oxford University Press, Oxford, pp 102–114
Otto M, Richters J (2007) Analysis of vegetation changes in high Andean wetlands using remote sensing as a contribution to environmental planning in southern Peru. In: Utilisation of diversity in land use systems: sustainable and organic approaches to meet human needs.

Tropentag October 9–11, Witzenhausen, 355pp. http://www.tropentag.de/2007/abstracts/links/Otto_NFHhoRkg.php
Palmer WC (1965) Meteorological drought. Research Paper 45. US Weather Bureau, Washington, 58pp
Pfost D, Casady W, Shannon K (1998) Precision agriculture: global positioning system (GPS). Missouri Precision Agriculture Center, University of Missouri, Columbia, 6pp
Ravelo AC (2008) Desarrollo de un sistema operativo para el monitoreo, evaluación y pronóstico de sequías en el ámbito del Organismo de Cuenca del Pacífico Norte. Area de estudio: Cuenca del Río Culiacán. [Developing an operational system for monitoring, assessing and forecasting droughts in the North Pacific Watershed Organism. Pilot area: Culiacán river watershed]. Final Report to WMO, Project PREMIA No. GINT 02/2008, 84pp + annexes
Ravelo AC, Pascale AJ (1997) Identificación de ocurrencia de sequías mediante imágenes del satélite NOAA e información terrestre [Identifying drought ocurrente using NOAA satellite images and ground information). Rev Fac Agron 17(1):105–107
Ravelo AC, Abril EG, Santa JA, Irastorza RO (2001) Cartografía satelital del potencial forestal del Valle de Calamuchita, Córdoba, Argentina [Satellite cartography of the forestry potencial of Calamuchita valley, Córdoba, Argentina]. XII Congresso Brasileiro de Agrometeorología y III Reuniao Latino-Americana de Agrometeorología. Fortaleza, Brasil (in CD)
Ravelo AC, De la Casa A, Ovando G, Planchuelo AM (2006) Modeling soybean and corn yields using ground and remote sensing information in Central Argentina. Proceedings of the 2nd International Workshop on Crop Monitoring and Forecasting in South America Montevideo, JRC/EU-FAO (in CD), Uruguay, 9–11 October
Ravelo AC, Planchuelo AM, Zanvettor RE, Ovando G, Barbeito A, Marraco G (2008) Boletin Agroclimático: Monitoreo, Evaluación y Pronóstico de Sequias en la Provincia de Córdoba, Argentina. [Agroclimatic bulletin: monitoring, assessing and forecasting droughts in Cordoba province, Argentina. Ministry of Agriculture] (www.cba.gov.ar)
Rojas O (2007) Operational maize yield model development and validation based on remote sensing and agro-meteorological data in Kenya. Int J Remote Sens 28(17):3775–3793
Sabins FF (1997) Remote sensing – principles and interpretation, 3rd edn. Freeman, New York, 494pp
Sakamoto T, Yokozawa M, Toritani H, Shibayama M, Ishitsuka N, Ohno H (2005) A crop phenology detection method using time-series MODIS data. Remote Sens Environ 96:366–374
Schmidt M, King EA, McVicar TR (2006) A user-customized web-based delivery system of hypertemporal remote sensing datasets for Australasia. Photogramme Eng Remote Sens 72: 1073–1080
Singh S, Brunini O, Singh D, Abramides PG, Rolim G, Pântano AP, Blain GC, Brunini APC, Ribeiro RV (2008) Online outreach of integrated weather based agricultural information system for sustainable agriculture through regional approach. Agrometeorological Series/2008/IAC/CIIAGRO-1, Campinas, Sao Paulo, Brazil, 12pp
Stoney WE (1997) Remote sensing in the 21st century: outlook for the future. Proceedings of the International Geoscience and Remote Sensing Symposium (IGARSS), Singapore, August 7. http://rst.gsfc.nasa.gov/Sect21/Sect21_1.html
Thamm HP, Menz G, Kissiyar O (2001) Investigation of the land use/land cover change in the Upper Oue'me' catchment, Benin (West-Africa) for the set up of a coherent development plan. Geosci Remote Sens Symp 7:3209–3211
Thapa R, Borne F, Kusanagi M, Cu PV (2004) Integration of RS, GIS and AHP for Hanoi peri-urban agriculture planning. Proceedings of the "Map Asia 2004" meeting, Beijing. http://www.gisdevelopment.net/application/agriculture/overview/ma04149.htm
Thornton PK, Bowen WT, Ravelo AC, Wilkens PW, Farmer G, Brock J, Brink JE (1997) Estimating millet production for famine early warning: an application of crop simulation modelling using satellite and ground-based data in Burkina Faso. Agric For Meteorol 83:95–112
Van Rossom J (2009) North-South axis. A developing cooperation. Research*eu Nr 61 of July. http://ec.europa.eu/research/research-eu/61/article_6116_en.html

VITO (2008) GEONETCast for and by Developing Countries project. Funded by the European Community's 7th Framework Programme for Research and Technological Development (FP7), pp 1301–1306

Werle D (2000) Flood and coastal zone monitoring in Bangladesh with Radarsat ScanSAR: technical experience and institutional challenges. Johns Hopkins Apl Techn Digest 21(1): 25

Zin I, Zribi M, Mascle-Le Hégarat S, Ottlé C (2003) Multi-captor remote sensing for an integrated vegetation – hydrological model: preliminary results. Geophys Res Abstr 5:12317

Zoffoli ML, Kandus P, Madanes N, Calvo DH (2008) Seasonal and interannual analysis of wetlands in South America using NOAA-AVHRR NDVI time series: the case of the Parana Delta Region. Landsc Ecol 23:833–848

IV.20 Geoinformatics for Evaluating Erosive Rainfall Hazards in Uplands Crops: Preliminary Decision Making

Nazzareno Diodato, Michele Ceccarelli, and Gianni Bellocchi

At a preliminary stage of decision making it is timely to work with parsimonious models, i.e. models with few components that explain the process under study with few factors that interrelate substantially (Box IV.24). We advocate using geoinformatic models (after Warren et al. 2000), which are specific by their geometry, data organization, and degree of generalization. In this study, Soft Geoinformatics Modelling (SGM) makes use of geostatistical GIS application to map erosive rainfall hazards for situations where data collection is limited. SGM was tested at a Mediterranean agricultural landscape, where a hydroclimatic erosivity variable was explored via geostatistical ordinary indicator kriging (oIK) approach for characterizing the variability of severe erosion.

Box IV.24

Natural climatic variability (along with variability in soil properties, topography and land-cover) makes it difficult to estimate land degradation. This is especially true for mountainous agricultural environments, where it manifests itself in a variety of processes (Shrestha et al. 2004). Land degradation is sensitive to the effects of annual weather variability (Mulligan 1998). Erratic rain storms impact on soil hydrology of mountainous croplands (where they are likely to occur in significant amount), causing high-magnitude geomorphological processes and disastrous erosional soil degradation (García-Ruiz et al. 2000). The interannual variability of storms is important to assess changes in the power of rainfall (rain erosivity), the latter being a driving force of several hydroclimatic and erosive processes (Le Bissonnais et al. 2002).

Assessments of this type require the support of modeling tools, although they differ greatly in complexity and input requirements (Merritt et al. 2003).

N. Diodato (✉)
TEDASS-Technological Interdepartmental Center for Environmental Diagnostics and Sustainable Development, University of Sannio, Benevento, Italy
e-mail: nazdiod@tin.it

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0_120,

A multi-criteria approach can be an option for scenarios where decision making is complex due to a variety of conflicting goals (Saroinsong et al. 2007). At a preliminary stage of decision making, however, it is timely to work with parsimonious models, i.e. models with few components that explain the process under study with few factors that interrelate substantially (after Mitra et al. 1998; Boggs et al. 2001).

Kriging is a generic name, adopted by the geostatisticians for a family of generalized least-squares regression algorithms. A related major area of interest and application of nonparametric estimation of conditional distribution is the indicator kriging (IK) technique, that is seen as mainstream and conventionally the predictable refuge of those who simply need robust interpolations of erratic spatial phenomena (Isaaks and Srivastava 1989).

The practice of IK involves calculating and modeling indicator variograms $2\gamma_I(\mathbf{h}; z_k)$ (that is, variograms of indicator-transformed data) at one threshold or at a set of cut-offs (z_k) (Glacken and Blackney 1998). In other words, $2\gamma_I(\mathbf{h}; z_k)$ measures the transition frequency between two classes of z-values as a function of $\mathbf{h}$ (Goovaerts 1998), where $\mathbf{h}$ is the *lag* vector as a distance class interval used for variogram computation, and z is the generic variable. The latter is in our case the Erosivity Hydroclimatic Index (EHI).

Another important element of a variogram is the *range*, that, for a spherical, hole-effect or bessel model, is the distance at which the model reaches its maximum value, or *sill*. As required, this variogram quantifies the commonly observed relationship between the values of the samples and those in the samples' proximity. Successively, this information is utilized for a kriging interpolation procedure at unsampled locations as a linear combination of the neighboring observations.

Geoscientists interested to predict spatially from their more or less sparse environmental data, can so take kriging methods as a promising approach to spatial support towards a finer scale mapping and spatial uncertainty assessment. For instance, among geostatistical approaches used to quantify this uncertainty and to improve ecosystems management, kriging is becoming a recognized standard, applied in environmental fields as different as hydrology and agrometeorology (Diodato and Ceccarelli 2004; Diodato 2006; Diodato and Bellocchi 2008), soil-landscape modeling (Grunwald 2006), weather and climate (Dobesch et al. 2007).

Decisions rely upon critical values of environmental indicators. To illustrate the applicability of SGM, a classification was elaborated using a hydroclimatic indicator and a historical rain-erosivity series collected at 39 rain gauges in and around the Benevento province, southern Italy (Fig. IV.37a, b). The Benevento province is a mountainous agricultural area centrally located in the Mediterranean, extending over about 2,000 km^2 and including hundreds of little fluvial-torrential catchments.

The influence on precipitation of relief orography (ranging from 60 to 1,800 m a.s.l.) is more evident in the western district of Benevento, where annual val-

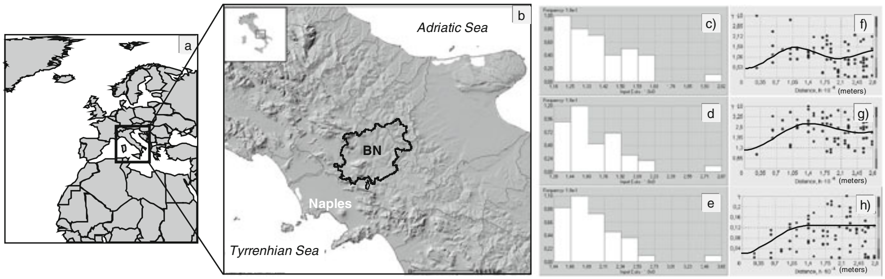


Fig. IV.37 Geographic location of the area under study (**a**) with zoom in of hillshade map, indicating Benevento province signed in *bold* (**b**); histograms EHI with return periods of 5 years (**c**), 10 years (**d**) and 20 years (**e**), and experimental indicator semivariograms (*dots cloud*) with a model of regionalization (J-Bessel *solid curves*) for EHI >1.59 and return periods of 5 years (**f**), 10 years (**g**), and 20 years (**h**)

ues exceed 1,200 mm. Lack of exposure to moist south-westerly airflow reduces precipitation in the eastern portion, with average value of about 800 mm year^{-1} (Diodato 2005). High-quality data covering the whole study-area were available for 1960–1985. Daily and sub-daily rainfalls were used as referred by Rossi and Villani (1995). Annual erosivity series were generated based on Diodato (2004). For SGM, a two-step process was developed: (i) Erosivity Hydroclimatic Index (EHI), (ii) geostatistical indicator coding.

This Erosivity Hydroclimatic Index (EHI) was developed assuming that the landscape has adapted to the natural hydrological regimen. Fluctuations in this regimen exceeding thresholds may have disastrous consequences for the agricultural environment. EHI was developed after Diodato (2006) to estimate the expected erosion hazard with assigned return period (RP):

$$\mathrm{EHI} = \frac{R^{*}{}_{\mathrm{RP}}}{f \cdot \mathrm{Med}(R^{*})} \tag{1}$$

where $R^{*}{}_{\mathrm{RP}}$ is the annual rainfall erosivity (MJ mm ha^{-1} h^{-1}) with assigned return period, estimated with Gumbel – Gringorten equation (Gringorten 1963); it represents the force that impinging rain exerts on the soil in relation to an expected hazard. Med(R^{*}) (MJ mm ha^{-1} h^{-1}) is the median of the annual erosivity; it represents a threshold for a natural hydrogeomorphological regimen. Coefficient f (assumed equal to 1) explains the degree of local ecosystem flexibility.

The second process assigns to the indicator $I(\mathbf{x}; z_k)$ at location $\mathbf{x}$, a value based on the estimated $z(\mathbf{x})$ value at the same location, based on the following rules, as defined by Diodato (2006):

$$I(\mathbf{x}; z_k) = \begin{cases} 1 \rightarrow z(\mathbf{x}) > z_k \\ 0 \rightarrow z(\mathbf{x}) \leq z_k \end{cases} \tag{2}$$

Based on our local experience, we used the threshold $z_k = 1.59$ (equal to the *EHI* median value) to delineate hazardous areas where moderate land use would be desirable and further investigation should be conducted. For each unsampled point, an oIK estimator based on Goovaerts (1998) was used, i.e. a linear combination of the $n(\mathbf{x})$ indicator $I(\mathbf{x};z_k)$ in the neighbourhood area to the $\mathbf{x}_0$ unsampled location.

Descriptive statistics and distributions of EHI are presented in Fig. IV.37c, d, e. The distributions are positively skewed (skewness ranging from 1.3 to 1.84), while the kurtosis is high and this is clearly evident in the histograms where the data do not follow a normal distribution.

A linear model for regionalization was fitted using a two-stage iterative procedure developed by Johnston et al. (2001). Stage 1 begins by adopting an isotropic and spherical semivariogram model on the scaled data with respect to the standard deviation. With stage 2 any parameter, i.e. number of *lag* (assumed equal to 7), *lag* size (assumed equal to 4,000 m), *range*, *nugget* and *sill* were calibrated interactively. Stage 2 accounts for unidirectional-dependent variability according to Fig. IV.37f, g, h, showing the experimental indicator semivariograms (dots) computed using 39 EHI data, and fitted curves for return periods of 5, 10 and 20 years, respectively. Semivariogram values increase with the *lag* distance, reflecting the assumption that climate erosive hazard data nearby tend to be more similar than data that are farther apart, reaching a maximum at 16,000–20,000 m before dipping on *sill* value. However, Fig. IV.37f (5-year return period) displays a complex dots cloud in an experimental semivariogram that reaches a strong hole-effect with small *range*, suggesting erratic spatial variability of EHI for short return periods.

Figure IV.38a, b, c shows 2,000 × 2,000 m grid maps based on the EHI threshold. The non-linear semivariogram J-Bessel function and *nugget* effect were selected as base model. The map indicates that the phenomenon accounted by oIK is not smooth (EHI values strongly change with distance). In addition, a GIS was used to add a group layer and geo-cartographic presentation of the final maps. Consequently, the layers delimiting the extent of the geomorphological impact were overlaid on 100 m terrain to the oIK maps which locate the areas probably subject to erosive hazard (probability >0.5 to exceed the threshold EHI $= 1.59$) (Fig. IV.38d, e, f).

Rainfall impact bands for 5-year return periods are focused on the small-scale topography (Fig. IV.38d). Especially for this return period it is difficult to explain the climate erosive hazard spatial variability at *lag* distance $<5{,}000$ m. The experience informs that the impact of rainfall not always spans large-scale territory. For a 10-year return period (Fig. IV.38e), EHI is composed of a pattern penetrating in large valleys, which could be most susceptible to calamitous thermoconvective activity.

For a 20-year return period, the whole Benevento province, with the exception of a small north-eastern portion, was classified as hazardous (Fig. IV.38f). For these severe erosion – prone lands, falling in sloped terrain, mitigation through conservation practices can only serve to become marginally prone because of the severe

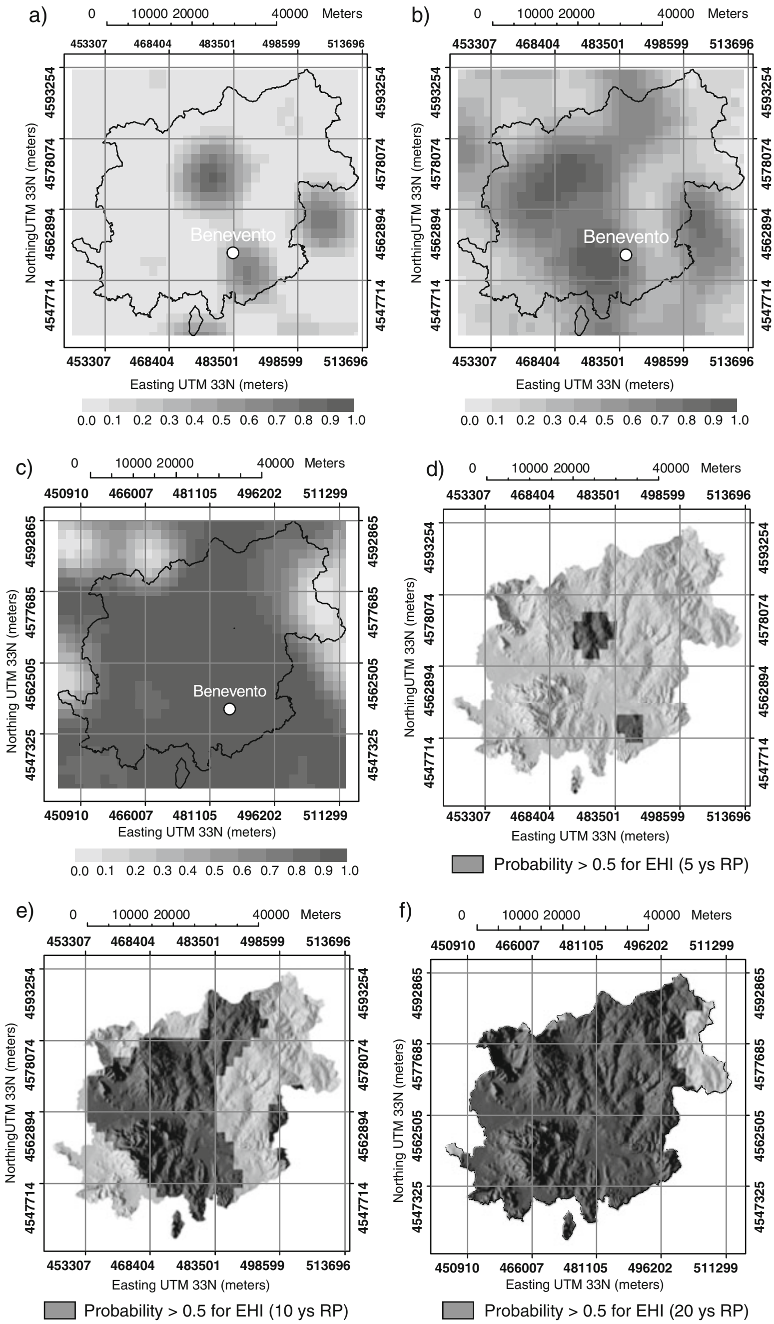


Fig. IV.38 Kriged probability maps of the EHI >1.59 with return periods to 5 years (**a**), 10 years (**b**), and 20 years (**c**), and kriged maps with probabilities >0.5 (severe erosion – prone areas) with return periods of 5 (**d**), 10 (**e**), and 20 years (**f**) overlain on 100 m hillshade-terrain for the Benevento province. The legend of the graphs **a, b** and **c** indicates the probability range geo-climatic limitations. It follows from probability mapping (Fig. IV.38d, e, f) that about 8, 58 and 90% of Benevento area is classified as hazardous, for 5, 10 and 20-years return periods, respectively.

Overall EHI-outputs have the advantage that they can be compared with the surrounding stations because the results are scaled and can be used in hazard maps. The disadvantage is that with the same probability to overcome a specific erosivity threshold, output maps may be of difficult interpretation when superimposed to lands with very different combinations of soil type, erodibility and cover.

Extreme erosive events have been observed as increasing in recent decades and they are expected to rise during warm periods. It is then important to gain a better understanding of the forcing mechanism and its predictability.

This work could be improved and developed considering some guidelines such as: (i) establishing a better knowledge of the rainstorm frequencies that may exceed specific thresholds (e.g. tolerable soil loss), and historical disaster records and (ii) employing a more inclusive planning process using a multi-criteria approach to select the appropriate land utilization types and planning agro-ecological land use.

References

Boggs G, Devonport C, Evans K, Puig P (2001) Gis-based rapid assessment of erosion risk in a small catchment in the wet/dry tropics of Australia. Land Degrad Dev 12:417–434

Diodato N (2004) Estimate RUSLE's rainfall factor in the part of Italy with a Mediterranean rainfall regime. Hydrol Earth Syst Sci 8:103–107

Diodato N (2005) The influence of topographic co-variables on the spatial variability of precipitation over little regions of complex terrain. Int J Climatol 25:351–363

Diodato N (2006) Spatial uncertainty modelling of climate processes for extreme hydrogeomorphological events hazard monitoring. J Environ Eng 132:1530–1538

Diodato N, Bellocchi G (2008) Drought stress patterns in Italy using agro-climatic indicators. Clim Res 36:53–63

Diodato N, Ceccarelli M (2004) Multivariate indicator Kriging approach using a GIS to classify soil degradation for Mediterranean agricultural lands. Ecol Indus 4:177–187

Dobesch H, Dumolard P, Dyras I (eds) (2007) Spatial interpolation for climate data: the use of GIS in climatology and meteorology. Wiley-ISTE, Hoboken, 284pp

García-Ruiz JM, Arnaez J, White SM, Lorente A, Begueria S (2000) Uncertainty assessment in the prediction of extreme rainfall events: an example from the central Spanish Pyrenees. Hydrol Process 14:887–898

Glacken I, Blackney P (1998) A practitioners implementation of indicator kriging. Proceedings of the Symposium on Beyond Ordinary Kriging, Perth Western, pp 26–39

Goovaerts P (1998) Geostatistical tools for characterizing the spatial variability of microbiological and physico-chemical soil properties. Biol Fertil Soils 27:315–334

Gringorten II (1963) A plotting rule for extreme probability paper. J Geophys Res 68:813–814

Grunwald S (ed) (2006) Environmental soil-landscape modeling: geographical information technology and pedometrics. CRC Press, New York, 488pp

Isaaks EH, Srivastava RM (eds) (1989) An introduction to applied geostatistic. Oxford University Press, New York, 561pp

Johnston K, Verhoef JM, Krivoruchko K, Lucas N (2001) Using ArcGis geostatistical analyst. ESRI Press, Redlands, 300pp

Le Bissonnais Y, Montier C, Jamagne M, Daroussin J, King D (2002) Mapping erosion risk for cultivated soil in France. Catena 46:207–220

Merritt WS, Letcher RA, Jakeman AJ (2003) A review of erosion and sediment transport models. Environ Modell Softw 18:761–799

Mitra B, Scott HD, Dixon JC, McKimmey JM (1998) Applications of fuzzy logic to the prediction of soil erosion in a large watrshed. Geoderma 86:183–209

Mulligan M (1998) Modelling the geomorphological impact of climatic variability and extreme events in a semiarid environment. Geomorph 24:59–78

Rossi F, Villani P (1995) Valutazione delle piene in Campania. Allegato: Tabelle pluviometriche. [Assessment of the flooding in Campania Region. Annex: Pluviometric Tables.] CNR–GNDCI, Presidenza del Consiglio dei Ministri, Dipartimento della Protezione Civile, Rome, Italy, 194pp

Saroinsong F, Harashina K, Arifin H, Gandasasmita K, Sakamoto K (2007) Practical application of a land resources information system for agricultural landscape planning. Landsc Urban Plan 79:38–52

Shrestha DP, Zinck JA, van Ranst E (2004) Modeling land degradation in the Nepalese Himalaya. Catena 57:135–156

Warren SD, Mitasova H, Jourdan MR, Brown WM, Johnson BE (2000) Digital terrain modeling and distributed soil erosion simulation: measurement for minimizing environmental impacts of military training (CS-752), Colorado State University, College of Forestry and Natural Resources, Fort Collins, 76pp. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA379446 and http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA379446&Location=U2&doc=GetTRDoc.pdf

Index

K. Stigter (ed.), *Applied Agrometeorology*, DOI 10.1007/978-3-540-74698-0,

E

G

H

O

Q

R