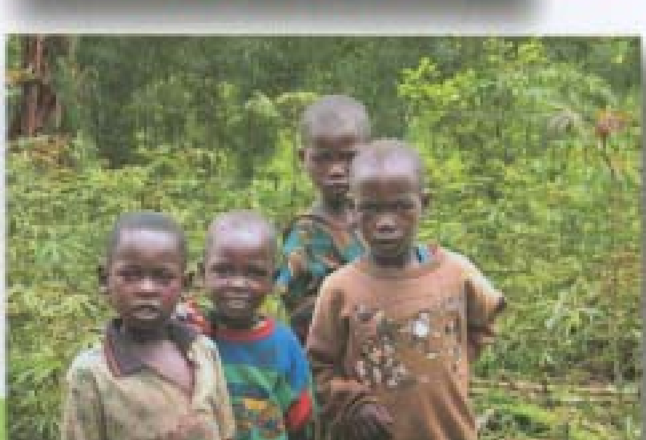
TSBF-CIAT's Achievements and Reflections, 2002-2005

The Tropical Soil Biology and Fertility Institute of the International Center for Tropical Agriculture (TSBF-CIAT)

Integrated Soil Fertility Management in the Tropics



CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

TSBF
The Tropical Soil Biology and Fertility Institute of CIAT (TSBF-CIAT)

About TSBF-CIAT

The Tropical Soil Biology and Fertility Programme (TSBF) was founded in 1984 to develop capacity for soil biology as a research discipline in the tropical regions, and to conduct research on the role of soil biology in maintaining or improving soil fertility and combating environmental degradation, on the premise that biological management of soil fertility is an essential component of sustainable agricultural development.

In 1997, the International Center for Tropical Agriculture (CIAT, or Centro Internacional de Agricultura Tropical) created a soils team in Latin America to focus on identification of strategic principles, concepts and methods for protecting and improving soil quality through the efficient and sustainable use of soil, water and nutrient resources in crop-pasture-fallow systems in tropical savannas and hillsides agroecosystems.

In December 2001, an agreement between CIAT and the TSBF Programme led to the latter's becoming an institute of CIAT (TSBF-CIAT). Today, the Institute operates as an integral part of the CIAT research programme, and the TSBF Director reports to the CIAT Director General. TSBF-CIAT staff are located in two major target areas in the tropics (Africa and Latin America), with the directorate housed on the World Agroforestry Centre (ICRAF) campus in Nairobi, Kenya.

The 2005-2010 TSBF-CIAT strategy is aligned with the **Millennium Development goal:** "to help create an expanded vision of development that vigorously promotes human development as the key to sustaining social and economic progress in all countries, and recognizes the importance of creating a global partnership for development." The strategy also encompasses the **CGIAR's agricultural and environment mission:** "to contribute to food security and poverty alleviation in developing countries through research, partnerships, capacity building and policy support, promoting sustainable agricultural development based on environmental sound management of natural resources." The strategy is also aligned with CIAT's three Development Challenges: (1) Enhancing and Sharing the Benefits of Agrobiodiversity, (2) Improving the Management of Agroecosystems in the Tropics and (3) Enhancing Rural Innovation.

TSBF-CIAT's programme goals are: to strengthen national and international capacity to manage tropical ecosystems sustainably for human well-being, with a particular focus on soil, biodiversity and primary production; to reduce hunger and poverty in the tropics through scientific research leading to new technology and knowledge; and to ensure environmental sustainability through research on the biology and fertility of tropical soils, targeted interventions, building scientific capability and contributions to policy.

TSBF-CIAT utilizes a range of approaches to achieve programme goals in collaboration with its partners, with particular emphasis on the following:

Catalysis: ensuring that partners are kept at the forefront of conceptual and methodological advances by conducting and promoting review, synthesis and dissemination of knowledge. This is done through workshops, training courses and sabbatical and short exchange visits.

Collaboration: developing appropriate alliances with institutions across the research, educational and developmental spectrum, including linkages between institutions in the North and South.

Facilitation: coordinating actions among partners to achieve progress and success in research. This is done by providing backstopping support in the preparation, submission, implementation and publication of research projects.

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1. Soil fertility. 2. Soil management. 3. Cropping systems. 4. Soil biology. 5. Soil organic matter. 6. Genetic resources. 7. Land management. 8. Socioeconomic environment. 9. Water management. 10. Capacity building. 11. Sustainability. 12. Organization of research. 13. Indigenous knowledge. 14. Traditional farming. 15. Planning. 16. Markets. 17. Tropical zones. 18. Africa. 19. Central America. 20. South America.

AGROVOC descriptors in Spanish:
1. Fertilidad del suelo. 2. Manejo del suelo. 3. Sistemas de cultivo. 4. Biología del suelo. 5. Materia orgánica del suelo. 6. Recursos genéticos. 7. Ordenación de tierras. 8. Entorno socioeconómico. 9. Manejo de aguas. 10. Creación de capacidad. 11. Sostenibilidad. 12. Organización de la investigación. 13. Conocimiento indígena. 14. Agricultura tradicional. 15. Planificación. 16. Mercados. 17. Zona tropical. 18. África. 19. América Central. 20. América del Sur.

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Contents

Executive summary

This document presents the achievements and reflections for the period 2002-2005 of the CIAT Tropical Soil Biology and Fertility Institute (TSBF-CIAT). As such, this document complements and updates the TSBF-CIAT Strategy Document "Integrated Soil Fertility Management in the Tropics: From Knowledge to Implementation".

Since its creation in 1984, TSBF has conducted foundational research on the role of biological and organic resources in tropical soil fertility, in order to provide farmers with improved soil management practices for sustainable increase in agricultural productivity. This is in recognition that soil fertility depletion is the fundamental biophysical cause for declining per capita food production in sub-Saharan Africa (SSA) and Latin America. In 1997, CIAT created a soils team (PE-2 Project) in Latin America to focus on identification of strategic principles, concepts and methods for protecting and improving soil quality through the efficient and sustainable use of soil, water and nutrient resources in crop-pasture-fallow systems in tropical savannas and hillsides agro-ecosystems. Agreement between CIAT and the TSBF Programme in 2001 led to the latter's becoming an institute of CIAT (TSBF-CIAT).

TSBF-CIAT is addressing the CGIAR System Priority Area 4: Promoting poverty alleviation and sustainable management of water, land, and forest resources. Majority of the efforts are dedicated to System Priority Area 4A: Promoting integrated land, water and forest management at landscape level. Considerable efforts are also dedicated to System Priority Area 4D: Promoting sustainable agro-ecological intensification in low-and high-potential areas. TSBF is housed in one of the three research for development challenges (RDCs) of CIAT, "Improving management of agro-ecosystems in the tropics". The project also works in close collaboration with the other two RDCs (Agrobiodiversity; Rural Innovation) of CIAT.

The comparative advantage of TSBF-CIAT is in conducting international public goods (IPG) research on Integrated Soil Fertility Management (ISFM) in farming systems where soil degradation undermines local livelihoods and market opportunities. However, while TSBF-CIAT will focus primarily on strategic research, it is also ready to conduct research for development with partners via regional networks and global projects. TSBF-CIAT will continue research on below-ground biodiversity (BGBD) as a means of beneficially managing soil biology, through the GEF-UNEP funded global project on BGBD which has successfully completed its Phase I and is about to start its Phase II activities. Much of the applied research and dissemination of findings, as well as NARSs capacity building, is conducted via the Institute's regional partner networks/consortia—the African Network for Soil Biology and Fertility (AfNet), the Latin American Consortium on Integrated Soil Management (known by its Spanish acronym, MIS), and the Consortium for Sustainable Development in the Andean Ecoregion (CONDESAN). TSBF-CIAT also collaborates with the South Asian Regional Network (SARNet) on soil fertility research in that region.

Research for development activities are conducted in close collaboration with a range of partners including NARES, ARIs, Universities, NGOs, private sector, and farmer groups/communities throughout SSA, Central America (Honduras, Nicaragua) and South America (Colombia, Brazil, Ecuador, Peru, Bolivia). In recent years this research has focused on a paradigm of Integrated Soil Fertility Management (ISFM). ISFM is a holistic approach to soil fertility research that embraces the full range of driving factors and consequences of soil degradation—biological, physical, chemical, social, economic and political (**Figure 1**).

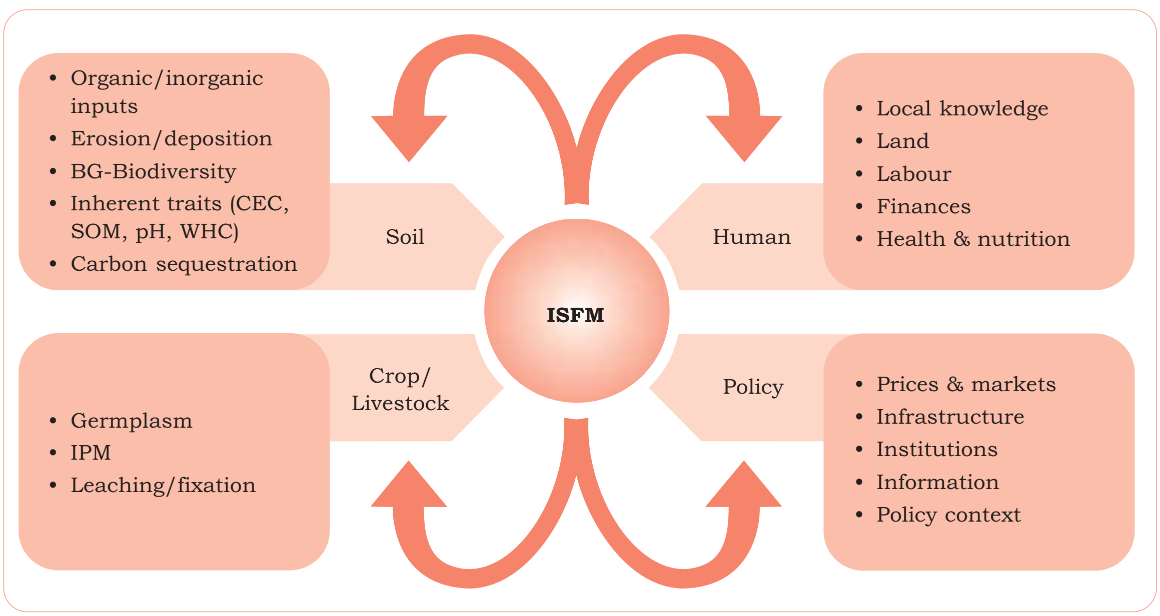


Figure 1. The processes and components of integrated soil fertility management (ISFM) [BG: below-ground; CEC: cation exchange capacity; SOM: soil organic matter; WHC: water holding capacity; IPM: integrated pest management].

However, successful resource management and sustainable agricultural productivity need to go still further, into the realms of markets, health and policies. The central hypothesis is that natural resource management (NRM) research will have more leverage if the apparent gaps between investment in the natural resource base and income generation can be bridged. Therefore, TSBF-CIAT's new strategy has been to take ISFM an additional step forward by addressing the full chain of interactions from resources to production systems to markets and polices—the "Resource to Consumption" (R-to-C) framework [547]. Under this framework, investment in soil fertility management represents a key entry point to agricultural productivity growth, and a necessary condition for obtaining positive net returns to other types of farm investments.

TSBF-CIAT is pursuing the following three objectives under our new strategy:

- To improve the livelihoods of people reliant on agriculture by developing profitable, socially-acceptable and resilient agricultural production systems based on ISFM.
- To develop sustainable land management (SLM) practices in tropical areas while reversing land degradation.
- To build the human and social capital of all TSBF-CIAT stakeholders for research and management on the sustainable use of tropical soils.

To achieve these objectives, all of TSBF-CIAT's work can be conceptualized using seven strategic pillars:

1. Improving fertilizer efficiency and developing soil and water management practices.
2. Improved germplasm as an entry point for managing soil fertility.
3. Managing the genetic resources of soil for enhanced productivity and plant health.
4. Understanding farm level social dynamics.
5. Linking farmers to markets, nutrition and health.
6. NRM strategies to move from plot to landscape scales.
7. Strengthening scientific and institutional capacity of partners for ISFM.

The following sections present the background, achievements, gaps, and potential opportunities and challenges for the research of TSBF-CIAT over the period 2002-2005 and are reviewed with reference to citations of work published (or in progress).

Four simultaneous separate but parallel Center Commissioned External Reviews (CCER) of CIAT were conducted during the period 8-19 May 2006. Three review panels assessed the three major program areas of CIAT, its RDCs: Sharing the Benefits of Agrobiodiversity. Enabling Rural Innovation and Improving Management of Agro-ecosystems in the Tropics (IMAT). TSBF-CIAT belongs to the IMAT-RDC. With few exceptions, the panels found the quality of the staff and of the research at CIAT to be high. The major substantive recommendations were: to more tightly focus the research program; to attain greater integration of that program; and to improve lines of authority and responsibility. Specific recommendations made by the review team and responses by TSBF-CIAT staff are given in Annex 1 and the TSBF-CIAT staff are listed in Annex 2.

1. Improving fertilizer efficiency and developing soil and water management practices

Background

The technical backbone of ISFM advocates the integration of mineral and organic sources of nutrients, thereby using locally available sources of inputs and maximising their use efficiency. TSBF-CIAT has embraced ISFM research to reverse land degradation and improve the livelihoods of people reliant on agriculture. What is needed is to break the cycle between poverty and land degradation in SSA by employing strategies that empower farmers economically and promoting sustainable agricultural intensification using efficient, effective and affordable plant nutrients. Such affordable management systems should be accessible to the poor, small-scale producers and the approach should be holistic and dynamic in order to foster both technical and institutional change.

Past research highlights

Soil characteristics

Nitrogen and phosphorus deficiencies are widespread in all SSA agro-ecosystems, with 80% of the soils deficient in P despite the availability of phosphate rocks in many parts of the continent. The main research highlights on soil characterization in the recent years have been on soil fertility gradients within farms [59, 72, 74, 116, 120]. While these studies have shown strong relationships between households' social categories, their production of organic materials, and the intensity with which inputs are applied to "homefields" or "outfields", variance of soil fertility status within farms is much greater than that

observed between farms. For example, in Western Kenya, 58% of the variance in soil organic C was due to variability within farm compared to only 9% for variability between farms [74]. Total N decreased in all sites with distance to the homestead (from 1.30 to 1.06 g/kg), as did Olsen-P (from 10.5 to 2.3 mg/kg). Grain yields in the no-input control plots followed the decrease in soil fertility status with distance to the homestead (from 2.59 to 1.59 t/ha). In the NPK treatments, however, this difference between field types disappeared (from 3.43 to 3.98 t/ha), indicating that N and P are the major limiting nutrients in the target areas [116]. In another study in the drylands of Niger, West Africa, variation of soil C at farm level ranged from 0.1% to 3.2% from the bush fields to the homestead. The fertilizer use efficiency increased with increasing soil C, indicating the need to improve soil with organic amendment in order to increase the fertilizer use efficiency [287].

Similar soil constraints (soil acidity, aluminium toxicity, P and N deficiencies) are the major chemical constraints together with soil compaction and erosion as physical constraints for crop-livestock production in tropical savannas of Latin America. In acid savanna soils of Colombia, deep-rooted tropical pastures enhanced soil quality by improving the size and stability of soil aggregates when compared with soils under mono-cropping. Increasing intensity of production systems resulted in improved soil physical conditions but decreased soil organic matter (SOM) and macrofauna populations with the exception of agropastoral systems evaluated where an overall soil improvement was observed [122, 220, 236].

Nutrient dynamics and turnover

Several studies addressed the dynamics of N, P and C in the soils across the different agro-environments and sustainability indicators were determined from long-term soil fertility management trials [8, 220, 236]. The rate of decline of soil C has been determined and the importance of the fine fraction in the protection of soil organic carbon assessed. The use of vertical tillage and agropastoral treatments contributed to the build-up of an arable layer in low fertility savanna soils of the Llanos of Colombia as indicated by improved soil physical properties and nutrient availability [55, 517, 518]. Influence of contrasting agropastoral systems and related P fertilizer inputs on size of P fractions in soil and their isotopic exchangeability were determined in acid savannas of Colombia and the results showed that organic P dynamics are important when soil P reserves are limited [211]. Recent work has shown that additions of charcoal to low fertility, acid Oxisols increases soil pH, cation exchange capacity, BNF and availability of various soil nutrients and result in a net increase in crop and plant yield. Another significant achievement was that the nitrification inhibition activity of accessions of *Brachiaria humidicola* was similar to the commercial apomictic cultivar indicating the possibility for genetic regulation of this important trait to improve nitrogen use efficiency in crop-livestock systems [318].

Interaction between organic and mineral plant nutrients

The quality of organic inputs and their interaction with mineral fertilizers have been the main focus [161, 162, 175]. A decision tree for selecting organic inputs for nitrogen management have been developed based on their N, lignin and polyphenol contents [51], as has one on manure use in southern Africa [39]. Fertilizer equivalency values of organic materials have been determined and it was found that organic leaves of Tithonia, Senna and Tephrosia had fertilizer equivalencies near 100% [82]. Decision guides have been developed in response to on-farm adaptive research that translate into simple assessments of resource quality to be used by extension agents and farmers, which have been tested with community-based learning activities [112]. Combining organic and mineral inputs has been observed to sometimes result in added benefits in terms of extra crop yield, compared with sole applications of organic and mineral inputs at equivalent rates [78]. In some cases, these benefits were the result of improved soil moisture conditions or reduced wind erosion after application of organic inputs [11, 78, 80, 89]. In other cases, however, mechanisms underlying the creation of positive interactions were not understood.

Addressing P deficiencies through micro-dose applications and phosphate rock

Except for a few phosphate rocks (e.g. Tahoua in Niger, Tilemsi in Mali and Mijingu in Tanzania), most of the phosphate rocks in Africa are low in reactivity and not suitable for direct application. Field work indicated that the P use efficiency from the unreactive rocks can double when phosphate rock was combined with the micro-dose technology. The dry mixture of 25% of P as water soluble P and 75% of P as phosphate rocks gave yields comparable to the use of 100% water soluble P [330].

Research on the micro-dose application of fertilizers has focused on evaluating and promoting point or hill application of 4 kg P/ha at planting time of millet and sorghum [233, 330]. The combination of strategic hill application of fertilizer with complementary institutional and market linkages, through an inventory credit system ("Warrantage") offers a good opportunity to improve crop productivity and farmers' incomes [233].

Water and nutrient use efficiency

The considerable research invested in water harvesting techniques (e.g. the zaï, stone bunds, contours, tied ridges, etc.) frequently neglects the role of soil nutrients, which in many cases are the most limiting factors. Our research in nutrient and water harvesting in Western, Southern and Eastern Africa has clearly indicated that application of nutrients greatly increased the water use efficiency [100]. In Ethiopia, extremely eroded farm plots were not responding to direct application of organic biomass, however, use of "zai" (small ditches to trap water and nutrients) increased yields up to 450% in comparison to the control [120].

Fertilizer efficiency in conservation agriculture

Given the successes of conservation agriculture in Latin America and elsewhere, AfNet has established network field trials of various conservation agriculture options in 12 sites in East and West Africa. Crop yield was lower with no-till than with tillage practice in continuous cereal, intercropping and rotation systems. There was no difference in maize yield between no-till and tillage practices when crop residue was added in the no-till in Western Kenya. In Burkina Faso, even with crop residue, no-till had lower yields compared to tillage practice and this is attributed to the crusting nature of these soils. Nevertheless, taking advantage of the reduced labour in the no-till, it is likely that the no-till could be more profitable.

Developing soil and water management strategies

The concept of "building up an arable layer" of improved soil quality addresses the physical and chemical constraints of acid savanna soils, using corrective tillage, amendments, and fertilizers, and deep-rooting plants in rotational systems to recover water and nutrients from the subsoil. Such arable layer technologies lay a foundation for implementing no-tillage systems on infertile tropical soils; research in close collaboration with CORPOICA and other partners in the Llanos of Colombia show the concept is both technically feasible and economically attractive to farmers [5]. Long-term field experiments are testing the effects of grain legumes, green manures, intercrops and leys as possible components that could increase the stability of systems involving annual crops. No-till treatments have consistently provided lower bulk density, higher total porosity, and significantly higher maize yields than the minimum tillage system. Maize yields on native savanna soils were also markedly lower than in the rest of the treatments, indicating the need for improved soil conditions in subsoil layers for root growth of maize [55, 94, 303, 404].

Challenges and new opportunities

- Increase fertilizers' use efficiencies in order to make them more profitable.
- Contribute to the development of the local fertilizer sector through feasibility studies (e.g. on the use of the indigenous phosphate rocks).
- Investigate and quantify fertilizers' effects on global change, green house gas (GHG) emissions, water quality, deforestation and land degradation, interactions with pest and diseases and carbon sequestration.
- Use decision support tools to improve fertilizer use efficiency (e.g. NuMaSS expert system). Field trials conducted in Nicaragua and Honduras have shown

that farmers can optimise fertilizer use when they take into account previous crop management, crop and soil characteristics, expected yields and resources available.

- For the concept on building an arable layer to be functional, more attention needs to be given to the driving forces behind farmer decision making and the existing policies for intensifying agriculture on infertile savanna lands.

2. Improved germplasm as an entry point for managing soil fertility

Background

The traditional starting point for soil fertility management is developing options that improve nutrient availability (i.e. the *supply of nutrients*). Whilst the research that TSBF-CIAT has conducted along this logic has added much to our knowledge of these processes, it is increasingly recognised that investments in soil fertility can only realise their potential in the presence of plants that are able to incorporate nutrients in their biomass (i.e. with sufficient *demand for those nutrients*). For example, given the soil acidity and soil physical constraints in tropical savannas, CIAT researchers realized that selection and development of acid tolerant crop and forage germplasm was the logical way to manage low fertility acid soils and to contribute to food security and poverty alleviation. In close collaboration with rice, beans, forages and other CGIAR commodity programs and regional partners, significant research for development efforts were made to introduce, test and disseminate productive and adapted germplasm. Finally, it should be noted that due to the short-term benefits associated with improved varieties, targeting better soil fertility management in integration with such varieties usually results in immediate interest from farming communities. Consequently, the integration of resilient germplasm is a full component of the ISFM research for development paradigm.

These improved crop and forage germplasm options interact with rural livelihoods and soil fertility management in a number of ways: (1) through direct improvement of the natural resource base (soil fertility, soil and water retention), e.g. by integration of legumes in

existing cropping systems and dual purpose live barriers, (2) through enabling crop production under conditions where local germplasm produces little yield, e.g. by integration of acid-tolerant varieties on soils with low pH, novel crop rotation system, (3) through generation of cash income that maybe re-invested in soil management, and (4) through provision of nutrient-dense (biofortified) edible components that can substantially enhance the health status of people engaged in agriculture with obvious consequence on the availability of labour.

Achievements

Managing biomass

The original mandate of TSBF in Africa before joining CIAT focussed on the management of organic inputs, rather than their production *per se*, the latter being the mandate of the institutes that are engaged in breeding activities. These activities culminated in the development of the Organic Resource Database, the Decision Support System for Organic N Management, and initiatives aimed at validating these concepts [39, 51, 81, 82, 120]. While validating the above concepts with farmers, it became apparent that most organic inputs available at the farm level are of medium or low quality and that the total amount of organic resources available was insufficient to sustain or increase production. The mandate of TSBF-CIAT therefore broadened to include activities aimed at producing organic resources, such as the integration of N-fixing legumes, among them, Mucuna and other cover crops [28, 29, 43, 155], cereal-legume rotations, (e.g. cowpea-sorghum in West Africa [97, 123], maize and soybean in southern Africa [156]).

Through these activities, it also became apparent that not all legumes grow equally well across all plots within a farm and that farmer interest in certain legumes was driven by issues far beyond soil fertility improvement in itself. Niches can be identified at the farm and landscape scale where specific production options can be optimized, applied and evaluated [1, 13, 43, 112, 142, 143, 150, 151, 154, 155, 156, 183]. In Latin America, fertilizer availability is greater and emphasis on biomass production is lower, except when used to improve soil fertility in planted fallow systems. Short-term planted fallows on volcanic ash soils in the Andean hillsides restored soil fertility by enhancing nutrient recycling through the provision

of SOM. Field and greenhouse studies indicated that a significant diversity exists in decomposition and nutrient release patterns of several organic materials and highlighted the value of screening new farming system components to achieve efficient nutrient cycling [19, 20]. *In Vitro* Dry Matter Digestibility (IVDMD) was identified as a quality parameter of plant materials that significantly correlated to nutrient release rates [19, 76, 77] and can be easily and cheaply used to assess forage quality in animal nutrition studies to predict decomposition and N release. Studies on the impact of improved fallows on soil fertility also indicated that *Tithonia diversifolia* slash/mulch system has the greatest potential to improve SOM, nutrient availability, and P cycling because of its ability to accumulate high amounts of biomass and nutrients [6] possibly due to strong symbiotic association with arbuscular mycorrhizal fungi [8, 56, 68, 220]. The *Calliandra calothyrsus* slash/mulch fallow system proved to be the most resilient as it produced similar amounts of biomass independent of initial level of soil fertility and was thus a candidate for wider testing as a potential source of nutrient additions to the soil and to generate fuelwood for resource-poor rural communities.

Germplasm adapted to low fertility conditions

Specific constraints to crop production can halt the utilisation of other nutrients that are not in short supply. Germplasm that is adapted to adverse biotic and abiotic stresses have been evaluated in various regions—e.g. new Lablab accessions [43], aluminium-resistant beans and Brachiaria grasses [40, 60, 117, 209, 220, 316],

drought tolerant crop and forage options [2, 3, 229, 447, 448], herbicide-resistant maize for striga control, dual purpose soybean varieties [64, 125], tissue culture bananas inoculated with specific arbuscal-mycorrhizal fungi [104], and acid soil adapted crop and forage options to the tropical savannas of Latin America [168, 317]. New drought tolerant beans, upland rice for hillsides and early maturing soybeans are currently under testing in novel rotational systems hillsides of Nicaragua [122]. Genetic variability was found among accessions of *Brachiaria humidicola* regarding the nitrification inhibition activity of root exudates [149].

Linking improved germplasm to markets

Situating improved germplasm within a full context of economic, socio-cultural, and policy conditions has developed within TSBF-CIAT to the point that research on how to link improved germplasm is now a full-fledged strategic pillar of its own (cf. 2005-2010 Strategic Document and the discussion of "Linking farmers to markets, nutrition, and health" below). Whilst this is a new area, initial research has shown that linking germplasm demand to markets can greatly facilitate and guide research on technology choices and soil fertility constraints. Examples include the market-oriented evaluation, adaptation, integration of dual-purpose soybean in cropping systems in Kenya and Uganda [125, 126], and the evaluation of cowpea, sugar bean and soybean varieties linked to market types and market demand in Zimbabwe [137, 154]. Other activities have successfully developed and linked improved NRM with export markets though smallholder farmers producing for certified organic markets in Europe [286]. In Latin American hillsides, the approach has been to combine improved soil fertility management (high fertility trenches) with market oriented high value crops. Net income increased by several fold in prototypes developed in San Dionisio, Nicaragua [122].

Linking improved germplasm to nutrition

This theme is also a new research priority, but initial progress has focussed on understanding the implications of changing production priorities at the farm level on household food (energy and protein) security and their implication on nutrient balances and household income [4, 154].

Challenges and opportunities

Developing more profitable and resilient production systems in the coming years will require the application of the knowledge and understanding of nutrient management processes in the following areas:

- Managing biomass:

  (i) Quantification of the multiple benefits of organic inputs for specific environments;
  (ii) Quantification of the long term impact of organic resource quality on the quantity and quality of the SOM pool;
  (iii) Use of drought tolerant germplasm for increasing dry season feed supply and coping with climate change;
  (iv) Further evaluation of organic resource production options with farming communities in relation to their current and future priorities and constraints.

- Germplasm that is adapted to low fertility conditions:

  (i) Quantification of the overall contribution of improved germplasm to the sustainability and profitability of the systems and to rural livelihoods as a whole using simulation modelling tools and trade-off analysis (e.g. DSSAT, NUANCES, IMPACT, APSIM);
  (ii) Drought tolerance will be an increasingly important trait in new germplasm together with resistance to major biotic constraints.

- Linking improved germplasm to markets:

  Evaluating and quantifying the soil-based implications of the market-led hypothesis (e.g. does inclusion of improved germplasm result in better soil management practices or does it merely enhance nutrient mining? Does the increased income from market sales lead to increased investment in agriculture and NRM? Is it feasible to produce high value crops without investing in IPM+INM?)

- Linking improved germplasm to nutrition:

  (i) Evaluating relationships between soil fertility status, soil management practices, and the post-harvest and nutritional quality of the produce (especially for the much advocated bio-fortified germplasm (e.g. Zn and Fe-dense beans) promoted by the HarvestPlus challenge program);
  (ii) Investigating the linkages between improving access to high-quality (i.e. nutrient dense) diets and improved health status and labour availability at the household level.

3. Managing the genetic resources of soil for enhanced productivity and plant health

Background

Soil microbiology is facing a number of challenges in the new century. There are societal demands for more information on sustainable resource management in forestry, rangelands, and intensive agriculture, and on maintaining biological diversity in those ecosystems. Below-ground biodiversity (BGBD) is dramatically reduced when forests are converted to agricultural land, and when agricultural land use is intensified. Reduced BGBD may decrease agricultural productivity and reduce the "resilience" of agricultural systems, which then become more vulnerable to adverse climatic events, erosion, pests, diseases, and other threats. Sustainable management of BGBD will enhance the resilience and sustainability of agro-ecosystems and, at the same time, help conserve soil genetic resources for bio-prospecting. The recognition of global climate change as a research priority raises many questions about the role of SOM and macro and micro-organisms in C cycling and the production and consumption of radiative gases. While there has been great progress in molecular biology and in the procedural aspects of genetic engineering, the problem is much more one of "what to do" rather than "how to do it".

Achievements

Conservation and sustainable management of BGBD

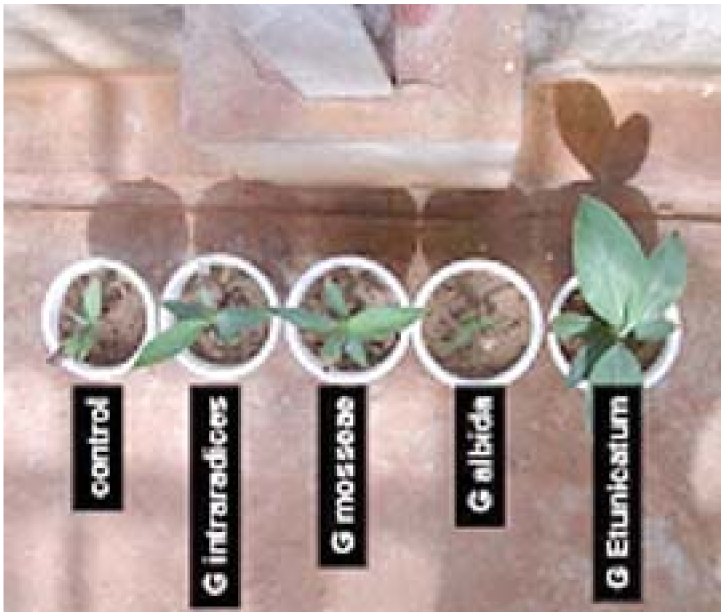
The urgency to slow down BGBD losses and better assess the potential uses of soil biodiversity in ecosystem management and bio-prospecting underpin the "Conservation and Sustainable Management of Below-Ground Biodiversity" (CSM-BGBD) Project. During the first phase, an inventory of soil organisms (from micro-organisms through macro-fauna, including bacteria, fungi, protozoa, insects, worms, and other invertebrates), has been carried out in the seven participating countries (Brazil, Côte d'Ivoire, India, Indonesia, Kenya, Mexico, Uganda) [164]. This inventory has identified and described many new species—e.g. 11 below-ground biota groups were recorded in Lampung, Indonesia: 53 ant genera, 59 beetle families/subfamilies, 37 termite species, 10 earthworm species, 44 collembolla species, 113 nematodes genera, 26 arbuscular mycorrhizae fungi/ AMF morphospecies, 9 plant pathogenic fungi genera, 4 lignin degrading fungi genera, 7 cellulose degrading fungi genera and 228 legume nodulating bacteria isolates. In some cases, these organisms may ultimately be useful to society (e.g. as inoculums for improving yields). For example, the inoculation of soil with earthworms for improving the formation of soil aggregates has been tested with promising results [200].

Utilization of soil micro-organisms such as rhizobia and mycorrhiza as inoculums

According to the importance of the soybean activities within TSBF-CIAT and the presence of a new staff soil microbiologist in TSBF-CIAT, some new activities have started on the utilization of rhizobial inoculums for improving plant growth. A soil Microbiology Laboratory has been set up in TSBF-CIAT (Kenya) where it is possible to isolate and cultivate rhizobial strains in both solid and liquid culture. Ongoing projects on both grain and tree legumes require the capacity to characterize the indigenous rhizobia present in the nodules harvested in the field. In the absence of indigenous strains capable of nodulating the host plant, we need to inoculate with selected rhizobia. Interesting results were obtained in the field with tree legumes [24, 36, 66]. With banana production, initial work has shown that it is possible to significantly increase the growth of banana plants produced *in vitro* (tissue culture) by inoculation with well-identified arbuscular mycorrhizal fungi (AMF) isolates.

Developing an integrated approach for soil fertility, pest and disease management

The combination of soil fertility and pest and disease management approaches provides a unique opportunity to exploit synergies allowing better control of these limitations to crop productivity [376]. Organic matter management can benefit soil biota (e.g. through erosion protection, nutrient cycling, control of pathogens) but can have complex impacts on the balance between the populations of harmful and beneficial organisms. Work studying pathogens, microregulators and microsymbionts during cultivation of common bean in soils infested with pathogenic fungi has shown that despite



the relatively limited time of green manure treatments, application of 6 t/ha of *Calliandra houstoniana* biomass to root-rot infested soil significantly reduced incidence (about 15%) and simultaneously increased yield (about 10%) in root-rot susceptible bean variety (A70) compared to control plots [519]. However, while application of *Tithonia diversifolia* reduced the root–rot incidence by close to 30%, it also reduced yield significantly. Further studies are in progress to understand the interactions among soil fertility, soil biota (pathogenic and beneficial), and crop yield.

Soil structure modification by soil biota

Soil structure influences multiple dimensions of soil fertility such as erosion, infiltration, drainage, water holding capacity and aeration, as well as nutrient and carbon cycling and biological activity. Earthworms, ants and termites constitute the soil macrofauna with greatest effects on soil structure while AMF, soil bacteria and plant roots have received increased attention in recent years as key determinants in soil aggregate formation and stabilization in the 'aggregate dynamic model'. This model directly links aggregate formation and breakdown in soils to the turnover of particulate organic matter (POM) as mediated by microbial and macrofauna activity proposes that in tropical soils several biological processes lead to the formation of "biological macroaggregates" through the activity of fungi and bacteria, plant roots and macrofauna (e.g. earthworms). Earthworms have pronounced effects on soil structure as a consequence of their burrowing activities as well as their ingestion of soil and production of biogenic structures or casts. Several studies have shown a strong relationship between AMF hyphal length and water stable aggregation in different soil types. Our studies in Colombia [144] have developed a bioassay in which we confirmed this relationship in volcanic-ash soils for a mixed inoculum. On going studies have focused on the functional diversity of three AMF genera (*Entrophospora, Gigaspora, Glomus*) in the production of external hyphae and soil aggregation [392].

A key question when trying to link soil organisms with their soil structure modification function is the need to define the origin of different types of aggregates found in soils and their temporal and spatial dynamics. Recent studies have developed a visual method to separate soil aggregates that is sensitive to land use change [152]. Additionally, the use of near infrared reflectance spectroscopy (NIRS) on visually separated soil aggregates in this study has also shown the capacity to link such biogenic structures to the organisms that produced them. This is a major step forward that will allow exploring the relative importance of soil organisms in soil structure modification as well as the study of their temporal and spatial dynamics as affected by land use change along intensification gradients.

Above-ground and below-ground biodiversity interactions

The "Quesungual" slash and mulch agroforestry system of southern Honduras presents an opportunity for studying the effects of trees on soil macrofauna dynamics in time and space [436]. While at a broad scale soil macrofauna communities are highly variable, preliminary results found positive associations between tree distribution (and tree management, such as pruning), the distribution of leaf litter, and the distribution of ant and earthworm activity. This has important implications for farm management, as it shows that farmers do not have to increase the density of large trees (which compete with crops for sunlight, water and nutrients) in order to increase litter cover and soil fauna activity.

In the seven CSM-BGBD project countries, the response of BGBD to different land use intensities varied from forest land to agricultural land. For example, the richness and abundance of ants, beetles and termites decreased with increasing land use intensification in Indonesia. Meanwhile, the abundance and biomass of earthworms were not affected by land use change, although intensification tended to reduce the individual earthworm size. "Exotic" earthworm species thrived in agricultural land, whereas "native" species were encountered only in forest. The ecological importance of exotic vs. native earthworms was unclear and will be studied in the second phase of the BGBD project. Nematode abundance was not affected by land use change although its richness decreased. Intensification reduced the AMF spore numbers but did not affect the richness of other fungi [164].

Challenges and opportunities

Building the capacity of partners in soil microbiology, linking soil biology and broader ISFM research (including integration with social science research), and improving communication and collaboration between partners in multi-site research.

- Linking the management of SOM and soil functions (ecosystem services) to either direct or indirect manipulation or control of soil organisms (e.g. CSM-BGBD, WOTRO, and MICROBES projects).

- Investigating the effects of climate change on land use and the soil's genetic resources (e.g. the effect of extreme oscillations in rainfall and temperature on nutrient cycling and biologically moderated carbon sequestration).
- Initiating new research on the biology of dryland soils, including micro-symbionts in dryland agroforestry systems (Gum Arabic) and the effects of climate change on dryland production systems.
- Improve understanding and opportunities for biological farming within the framework of ISFM.

4. Understanding farm level social dynamics

Background: An evolving Institute

From its beginnings, TSBF-CIAT has been known for leading edge biophysical research in soil fertility management. Its contributions to understanding the socio-cultural and gender dynamics of soil fertility have been more modest, but TSBF has been committed from its inception to including social sciences in its research agenda [446]. Pioneering work where social scientists took the lead in research addressed the dynamics of agrarian and land-use change [21], the gendered nature of ISFM decision-making [176], the role of social institutions mediating farmers' access to resources [520, 521, 523] and the interaction of local and scientific knowledge on soil fertility management [227, 228].

The growth of TSBF-CIAT and its expanding research agenda confronts the broader problem of a lack of social science research capacity (in our partner NARES as well as within CIAT) able to contend with NRM issues. Efforts to build rigorous social research capacity within AfNet, MIS, and within the partnerships of research projects are on-going but require sufficient resources and the support of multidisciplinary "champions" from outside the social sciences.

Socio-cultural research achievements

Indigenous knowledge and farmers' experimentation

Work addressing the existing knowledge base of local communities has been led by both social and biophysical scientists, in Latin America and Africa [7, 43, 93, 112, 153, 159]. These activities have served both to investigate and value local knowledge and to provide forums for studying the dynamics of the interaction between scientists and farmers. For example, understanding local soil management units has provided a logic for developing land-use plans [46] and for sampling soil biota [148, 436, 528]. On studying the dynamics of the interaction between local knowledge(s) and that of outsiders, the Strengthening "Folk Ecology" project in Western Kenya has tested and studied a community-based methodology with local partners and community groups [112]. Particular attention has been paid to how

knowledge is generated, shared, and withheld within social networks [216]. This approach uses on-going dialogue between scientists and farmers to build a "dynamic expertise" on soil fertility management that shares the strengths of disparate knowledge bases. Key outputs include: documenting ecological knowledge (including local indicators of soil quality and of ecosystem change); and empowering communities to continue conducting and evaluating ISFM experiments without the presence of a project.

Social and gender dynamics of land, livelihoods and soils

This body of research was started by Simon Carter and Eve Crowley, through their work on land use change and the role of off-farm income and social institutions in farming livelihoods and the sustainability of the soils in Western Kenya. The research explored the dynamics of special micro-niches on the farm high in soil fertility. The gender dynamics of land and livelihoods were researched further, with focus on the changing nature of the gender division of labour, land tenure and social relations [176]. This work further nuanced understandings of labour availability, the increasing demands to generate cash incomes and farmers' priorities and constraints. It also demonstrated how land tenure played a key role in determining how resources (especially soil fertility inputs) are invested in the special micro-niches high in soil fertility.

Methodologies

Another area of innovation has been in the area of methodologies. This has been carried out through the use of ethnographic work, the collection of personal narratives, participatory photography, on-farm experimentation, household typologies, social-network and diffusion mapping [28, 72, 133, 406, 424]. Many of the experiences of the Strengthening "Folk Ecology" project have been compiled as a Manual of Interactive Techniques [529], intended to serve not as a template for others to follow but to provide situated examples of how certain efforts at engaging researchers or farmers in experimentation succeeded or failed. Most recently, social scientific programming is including a special fund (the "Sikana fund", in memory of the late Patrick Sikana who first proposed the idea), equal to 5%-10% of total project funds that will give farmers the opportunity to decide for themselves how to invest the funds. How farmers choose to apply the funds will itself be part of the research process, and shed further light on their constraints and priorities, as well as the social dynamics (including the negotiated and contested nature of decision making).

Contributions of social scientific questions to biophysical research

Interdisciplinary collaboration ensures that social scientific research priorities and hypotheses inform and influence the broader bodies of biophysical research (and vice versa). Such co-learning can be immensely rewarding when it succeeds but must such efforts should not "drown out" social scientific research in it own right, which be carried out in conjunction and at the same time as this service provision role [214]. Examples of the positive influence of social scientific ideas within interdisciplinary projects include: (i) the analysis of the role of both social differentiation and local knowledge bases in the generation and maintenance of soil fertility gradients [72, 74, 133]; (ii) social scientific research in aspects of BGBD in all seven countries; (iii) plot to landscape level research (different scales, farm characterization and household characterization to target technologies) in Ethiopian highlands focusing on strengthening bylaws and collective action schemes for soil and water management [159]; (iv) research on the formation, restructuring, and scaling up processes of farmer field schools in Uganda and Kenya [43, 196].

Challenges and opportunities

- Social science in the lead role:

  (i) Gender and land tenure (expanding on past research, as well as contributing to work spear-headed by IDRC);
  (ii) Rural-urban linkages, resource flows and dynamics of vulnerability;
  (iii) Special micro-niches (soil fertility gradients);
  (iv) Relationship between indigenous and scientific knowledge;

(v) Improving the effectiveness and the depth of inter-disciplinary research and collaboration based on real lived experiences and desires of scientists within the institute (i.e. ethnography of science);

- Social science supporting other research actors:

  (i) Understanding the modification of technologies by farmers (understanding their motivation, drivers, reasons, list of priority technologies), feeding this back into the research process to motivate scientists in turn to modify and alter technologies according to their appropriateness and local context requirements);
  (ii) Local responses and adaptations to climate change (e.g. farmers' practices relating to green house gases and soil fertility gradients);
  (iii) Approaches and knowledge required for scaling out of technologies (e.g. how up-scalable are ISFM technologies and the farmer-scientist interactions).

- Documenting and show-casing the institutional memory of the Institute in terms of social science (a "social sciences symposium", interactions with the Anthro-No-Apology network—e.g. edited volume "Beyond the Biophysical" [166]).

- Developing other partnerships (e.g. with ERI, Latin America, AHI, AfNet) through NGOs, extensions, farmers groups, local-level partnerships.

5. Linking farmers to markets, nutrition and health

Background

In the past, increasing agricultural production occupied the central position in all agricultural development efforts. This emphasis held land as the most important factor of production and explains why agricultural productivity (yield) was commonly expressed in terms of output per unit area. Little attention was given to the productivity of the other traditional factors of production such as labour and capital. In the last few years this focus has changed in TSBF-CIAT, as the research for development paradigm has evolved and as it has been increasingly recognized that increased production alone cannot solve the multiple problems of smallholder

farmers. There is now strong research focus on improving their general livelihood dimensions (income, improved well-being, reduced vulnerability, improved food security, more sustainable use of natural resources, more access to external inputs, etc.). Linking farmers to markets, nutrition and health is an important entry point for improving livelihoods and address the fact that intensification of agricultural production cannot be sustained without linking farmers to input and output markets. Production has also been constrained through (i) unorganized marketing structures, whose conduct and performance has badly affected farmers' access to farm inputs and profitable agricultural production (ii) low value-addition (processing, grading, bulking, inspection, certification, standardization, branding, etc.) along the market chain has also reduced the profit potentials of farmers' agricultural production. Poor nutrition and health have also been linked with both inadequate farm labour availability and low factor (including labour) productivity, especially with the advent of HIV/AIDS pandemic. All these explain the need to link farmers to input and output markets, nutrition and health. Improvements in technology, with no change in the product that is to be consumed locally or traded, will not be sufficient to radically alter this situation. High value crops offer a solution to this problem.

Achievements

Whilst the majority of TSBF-CIAT's research outcomes have concentrated on production constraints, this strategic pillar of our research focus has only gained momentum in the last 2 years. Previous work in this area has been through support to broader CIAT-Africa research activities through their ERI program under the Rural Innovation Institute and has focused on the market-led hypothesis that tests whether increased incomes leads to increased investments in NRM [64, 283, 285].

High-value crops

Soybean: Results (unpublished) of the inventory data aimed at understanding why many past efforts to promote soybean (a well-known versatile crop) in the farming systems of Kenya led to limited success and impact on soybean development implicated: (i) low productivity, (ii) lack of know-how on soybean processing and utilization, and (iii) lack of markets. Following this understanding, we have developed an action plan and strategy to address problems of low productivity through farmer-led screening and participatory evaluation of improved promiscuous dual-purpose varieties obtained from the International Institute of Tropical Agriculture (IITA) in Nigeria. Farmer evaluation of eight dual-purpose soybean varieties tested in five locations in western Kenya identified varieties best suited to each environment and community. Only one variety (SB19) was ranked amongst the top four selected in each of the five locations. Some of the remaining varieties were only selected in specific locations.

With respect to lack of know-how on soybean processing and utilization and lack of market for soybean, we developed a "three-tier approach", for comprehensive soybean processing and market development in Kenya. The first tier is on household-level soybean market development centred on training on various processing methods for household food consumption. The second tier is a community-level soybean market development centred on soymilk production. A two-price scenario (pessimistic and optimistic price scenarios) analysis of soymilk production shows that this value addition leads to 4 to 14 times (US$1946-7069) more net returns than if the soybean is sold as grains without any further processing. The third tier improves on earlier work [433] on value addition, emphasizing the training of stakeholders on processing soybean into products with good market potential.

Gum Arabic: Although gum Arabic has a strong market potential, there are significant differences in the level of organization of its market (cf. Fagg and Allison, 2004). The contribution of TSBF-CIAT is the link to the effect of some microbiological interventions such as rhizobia inoculation and mycorrhiza symbioses on the survival and yield of the acacia trees producing gum Arabic.

Evaluating intensified nutrient management systems

Results from 2-year on-farm trials in Burkina Faso, Mali and Niger showed that average grain yields of millet and sorghum were greater by 44%-120%, while farmers' incomes increased 52%-134% when using hill application of fertilizer than with the earlier recommended fertilizer broadcasting methods and farmers' practice. Farmers using the "Warrantage" inventory credit system realized substantial net profits: revenue obtained from the micro-dose treatment was greater than that from the recommended practice (3x greater for millet, 2.5x greater for sorghum) [233].

The strategy in Latin America has been to work closely with other CIAT projects such as the Agro-enterprise project to identify most suitable crop-oriented options according to demands in local markets and the prevailing agro-ecological conditions. Selected crops (tomato and green pepper) were planted in Yorito, Honduras, and San Dionisio, Nicaragua, in high fertility trenches with combined organic and inorganic inputs [122]. Recent results showed a significant increase in gross income compared to traditional maize-bean rotations.

Niche markets (Certified organic and Fair-Trade)

An area of increasing interest for market linkages is through organic and Fair-Trade certification of production to take advantage of premium prices paid by exporters. Whilst it is recognized that this is a niche market that can not be entered into by all farmers, its potential as a growth market is huge and in turn this will impact on many more farmers: in Uganda expansion is around 20% a year, with 46,000 farmers currently certified. Examples from pilot sites in Uganda and Mozambique have shown how this approach has enabled farmers to access new market information (e.g. prices, quantities, quality) and new research products (e.g. disease resistant germplasm, variety evaluation for export, investing in natural resources and soil fertility) on critical aspects of production and how they have used this new information to develop competitive and profitable export organic agro-enterprises. Building farmers' capacities to learn about biological and ecological complexity using participatory approaches and involving farmers in experimentation is a critical success strategy for empowering farmers to be able to learn and to innovate [286, 291].

New challenges and opportunities

- Understanding and scaling up knowledge and methods to other crops and systems (e.g. the "three-tier" approach with soybean, the micro-dosing and "warrantage" revolving credit system).
- Quantifying the following relationships:

  (i) between good market access and soil fertility improvement;
  (ii) between HIV/AIDS and nutrition and HIV/AIDS and the consumption of soybean products;
  (iii) between soil fertility status and nutrition and between soil fertility status and postharvest quality of produce;
  (iv) between fertilizer use/soil fertility and food quality;
  (v) between bio-fortification and food quality.
- Ensuring the sustainability of the institutional linkages for promoting crops.
- Linking TSBF-CIAT activities with other regional and global initiatives.

- Linking productivity resulting from the manipulation of the biodiversity under the BGBD and Microbes projects with markets.
- Develop strategic alliances with the private sector to warrant economically beneficial prices and provide inputs for small farmers.
- Address trade agreements (CAFTA for Central America and TLC for Colombia) and diversification of current cropping systems with the introduction of high value crops under user friendly IPM and ISFM strategies.

6. NRM strategies to move from plot to landscape scales

Background

Land and resource degradation encompasses a complex of soil and water loss, nutrient depletion, depleted forest resources, scarce and inefficient water use, declining livestock contributions to the systems and infrastructure limiting access to markets. Up to very recently R4D actors did not also realize the need for developing various technological options for various landscape scenarios and the non-linear scaling relationships of different processes from plot to watersheds and from farmer to communities and vice versa. Plot and farm level interventions are typically less influenced by externalities (e.g. the need for collective decision and management of resources) than cross-boundary issues. Furthermore, the economic conditions and policy environment have not provided the necessary incentives for communities to make long term investments in better management of their resources to arrest this degradation scenario at plot, farm and landscape scales.

Achievements

Farm and landscape characterization to identify entry points

Farm and landscape characterization tools and models for targeting technologies in various farm niches have been tested and validated in both Africa and Latin America. Work with farmer research committees (FRC) in the highlands of East Africa (Ethiopia, Kenya, Uganda) has used scenario analyses to identify and characterize NRM constraints, landscape positions and production options, which can then be used to target suitable technologies and solutions [4, 28, 29, 118, 120]. Such interventions began rather conservatively with a focus on crop varieties but with ongoing support from modelling and scenario analysis FRCs have broadened to more complex issues, such as soil and water conservation with elephant grass contour strips, and farmer experiments with herbaceous and agroforestry legumes for fodder in improved dairy production, soil fertility and mixing early- and late-maturing maize varieties opened a niche for a legume relay [118]. Modelling in Ethiopia has also shown how the current risk of food insecurity and erosion could be reversed (while still satisfying household food and cash requirements) by reallocating land from low biomass producing cereal-dominated cropping to high biomass producing perennial food and cash crops [4, 119]. A decision guide which combined biophysical and socio-economic determinants was developed and validated to facilitate the identification of social and biophysical niches for the integration and landscape level adoption of legumes [182].

In the Colombian Andes, farm and landscape characterization was involved in the identification and classification of local knowledge about soils and their management [46]. The characterization of land-use distribution facilitated uncertainty analysis and risk management by local farmers (e.g. Potrerillo microwatershed of Cauca) [411, 477]). In the Amazon region, characterization and modelling tools have quantified the impacts of land-use change on soil C to enhance plant productivity and C sequestration in soils in areas where slash and burn is still

a common management practice [30]. Preliminary results from the Quesungual Slash and Mulch Agroforestry System (QSMAS) in Honduras indicated that soil losses under QSMAS of different ages (2, 5 and >10 years) were less than 2 Mg/ha in 14 weeks in comparison to the 30 Mg/ha soil losses observed in the traditional slash and burn control treatments [264]. Finally, application of these tools to the Llanos of Colombia and Venezuela has shown that intensification of agriculture, livestock and forestry in the region in the next 2 decades could result in a net increase of 160 Tg of C in the soil stocks, demonstrating the high potential of the region for providing environmental services [221].

Trapping nutrients at farm and landscape scales

In hilly landscapes soils and nutrients are washed away by run-off following heavy rains, particularly before crop establishment, and a strategy was tested to trap nutrients that could be otherwise lost. In farms where there is a tree cover and/or where the homestead is surrounded by perennial food and fiber crops at the head of the slope, nutrient loss in the outfields was successfully reduced by fast growing fallow crops (e.g. Vetch) while in farms where there was no vegetation at the head of the slope, nutrient could be trapped by fast growing multipurpose legumes and other herbaceous shrubs planted as a hedge at the lowest end and the middle of the slope following conservation ditches. Cut-and-carrying of this biomass can then effectively recycle nutrients to the original plots [8, 19, 181].

Methods for enhancing collective action

Work with partners and community-based organizations has highlighted the complexity of ways in which local and external factors can facilitate or impede collective action for ISFM [170, 213, 214, 323]. There are no general principles that obtain everywhere under all conditions, but generally working with existing institutions and networks is preferable to creating new structures. ISFM knowledge in many communities is treated as a privileged resource not to be shared indiscriminately, which means that scientists seeking to promote new technologies need to provide settings that validate both the new knowledge itself and existing knowledge [7], as well reinforcing the positive value of knowledge dissemination within multiple social networks [424]. Some farm-level activities provoked inter-farmer boundary conflicts (e.g. construction of soil bunds), which demand a process of collective management and negotiation to build the confidence needed to address higher-scale community issues. In Ethiopia, this scheme was used not only to organize labour and encourage the communities to put bunds, trees, waterways, etc. across the landscape, but also to develop and strengthen bylaws to help manage collective benefits [159].

Relating BGBD to land-use intensity at landscape scale

Work in the seven countries of the CSM-BGBD project (Brazil, Côte d'Ivoire, India, Indonesia, Kenya, Mexico, Uganda) has used comparative sampling with landscape level systematic grids to begin establishing and testing the relationships between land management intensity and BGBD [164]. The rich database (biophysical, biological and socio-economic) has data collected that transcends scales and can be ordered according to plot and landscape attributes that target differentiated beneficiaries some at plot level and others at landscape level. These experiences show the dependence of farmers on common land (e.g. BGBD project experience in India and Mexico where portions of community of land is set aside for shared interests such as for water catchments and other ecological and social needs). From this experience, lessons will be learnt on how to address land-uses that require communal participation and conservation at the landscape level.

Identifying opportunities for payment for environmental services

The project "Payment for Ecosystem Services" (financed by the Water and Food Challenge Program—WFCP) is applying a methodology for integrated watershed analysis in pilot watersheds of Colombia and Peru [113]. Scenario analyses of economic payments for ecosystem services determined the cost of each ton of reduced sediment. In the Miskiyacu micro-watershed, for example, it was calculated that only 2 months of payments were required to cover the cost of promoting coffee under shade in the prioritized area [443]. A multi-criteria optimization model permits ex ante analysis of multiple land-use options, calculating the socio-economic and environmental costs of changes in land use and technology under different spatial and temporal scenarios. This approach is being applied with stakeholders in analysing the five pilot Andean watersheds (Colombia, Ecuador, Peru and Bolivia), to support the identification of land use alternatives and management practices that internalize externalities [173].

One of the key elements in devising payments or compensation schemes for environmental services is through knowledge about the environmental service itself and the changes or modifications this is facing [443]. This is the case for the water quality of Fuquene Lake in Cundinamarca, Colombia, which is eutrophying with nutrients from urban and agricultural activities. Research with multiple partners is clarifying the origin and quantities of pollutants, using standard monitoring and modelling techniques as well as the use of stable isotopes [113, 173, 440, 442, 443].

Landscape indicators of soil quality

To accelerate interpretation of soil quality, NIRS analysis methods have been validated for different agro-ecosystems in both Colombia and Kenya [69, 72, 83, 152]. The calibration of different NIRS signatures with soil chemical and biological properties show the high potential of NIRS for evaluating soil quality in large areas, rapidly, reliably and economically, thereby facilitating decision-making with respect to soil management and conservation.

Challenges and future directions

- Addressing soil fertility and carbon-sequestration and GHG emissions at higher scales (e.g. new project to rehabilitate degraded lands through silvopastoral systems and reforestation with native timber species in the Caribbean savannas of Colombia under the Biocarbon Fund).
- Erosion and water management at higher level (addressing conflicts because of erosion and deposition, Upstream down stream conflicts).
- Under what conditions will the landscape level interventions work and under which conditions will it not work (e.g. fragmented land ownership across watersheds makes it difficult to consolidate landscape level activities and interventions).
- Convincing farmers to invest in collective action at landscape level using cross-boundary technologies and interventions.
- Building the case for farmers and communities to participate in BGBD conservation at landscape, regional and global levels (based on BGBD processes and expected benefits).
- Trade-offs between economic considerations and environmental concerns (i.e. degradation/regeneration) for selected interventions (e.g. growing *Eucalyptus* spp.) on the landscape vs. the economic benefits presented by presence of the trees.

7. Strengthening scientific and institutional capacity of partners for integrated soil fertility management

Background

Most African countries allocate less than 2% of GDP for agricultural research and the annual growth in agricultural research spending since 1990 has continued to decline. This situation is similar in Latin America, except in Brazil. Most NARES in both SSA and Latin America have therefore suffered a dramatic reduction in human and financial resources. Tertiary education has also not been spared the erosion caused by decades of underinvestment, loss of staff incentives and failure to recruit replacements for an ageing cadre of professors. Education programmes in agriculture, forestry and environment delivered to most scientists use dated, narrowly defined, and specialized perspectives that do not produce scientists with the scope and analytical skills and techniques needed to solve real development issues.

TSBF-CIAT established its AfNet in 1988 to exploit the advantages of networking as a means of building the capacity of African institutions to conduct interdisciplinary ISFM research at regional and international levels. The Consortium for the Integrated Management of Fragile Soils (MIS) in Central America was likewise formed in 1998 with the participation of 19 institutions that embraces the full spectrum of research, education and development. These two networks are adopting participatory and gender perspectives in research, technology testing and adaptation in addition to conducting process research. Partnerships, collaboration and multidisciplinary approaches are enabling a holistic and comprehensive problem and opportunity analysis, taking into account different stakeholder perspectives and socio-economic limitations to solutions. Both networks are increasingly adopting a market-oriented approach in order to diversify production systems and support ISFM through increased farmer income.

Achievements

Field research

A range of network trials are being implemented in over 100 sites across SSA. Implementation of the trials is undertaken by scientists and partners from NARES.

Such network trials cover all aspects of the ISFM research agenda and contribute significantly to the strategic understanding of how specific management options perform, as influenced by agro-ecological conditions. Research activities include management of mineral and organic inputs, the integration of legumes in cropping systems, biological nitrogen fixation, BGBD, conservation agriculture and soil and water conservation. The research highlights from these trials have been presented in previous sections of this report.

In the case of MIS, partners developed a common logical framework that put emphasis on three aspects: (1) collection and synthesis and of available information of soil, water and nutrient management in hillsides of Honduras and Nicaragua, (2) development of improved management systems and (3) dissemination of improved practices with the participation of stakeholders and strengthening the capacity of stakeholders to conduct research and validation. Six reference sites were identified to conduct collaborative research and networking activities, which have been followed up with annual planning meetings conducted with the participation of 474 participants from 76 institutions (4 CGIAR centres, 10 ARIs, 10 NARES, 11 Universities and 41 NGOs).

Degree-related training

Human capital development continues to be an integral part of most TSBF-CIAT activities. The research agenda is achieved through MSc and PhD research included in most research for development project work, conducted at regional public universities and elsewhere, followed by research support from the networks (AfNet, MIS and BGBD) for recent graduates on return to their home institutions.

- In Africa a total of 101 MSc and PhD students have been trained during the period.
- In Latin America, a total of 64 BSc, MSc and PhD students have been trained.
- An innovative initiative between AfNet and the International Foundation for Science (IFS) has helped young MSc and PhD graduates throughout SSA to develop project proposals for IFS funding on TSBF-CIAT's major research and development themes. At present about 20 researchers have received the grants and this effort will be further strengthened.

Short term training courses

Since 2002, AfNet has successfully organized five training workshops to broaden the capacity of scientists working in the NARES, universities and other organizations. The courses include: one training course on "Nutrient Monitoring (NUTMON)", two training courses on "Participatory research and scaling up" and two other training courses on "DSSAT Version 4: Assessing Crop Production, Nutrient Management, Climatic Risk and Environmental Sustainability with Simulation Models". AfNet in collaboration with the International Atomic Energy Agency (IAEA) also held a workshop on the use of isotope techniques to monitor land degradation.

The Below-Ground Biodiversity Program (BGBD) has also organized a range of international training workshops on: "Ecology and taxonomy of termites and ants", "Arbuscular Mycorrhizal Fungi (AMF) and Ectomycorrhiza (ecology, taxonomy and methods of inventory)", "Ecology and taxonomy of earthworms", "Nematodes", and a training course on "Molecular techniques for BGBD".

Training courses organized by MIS include: soil quality indicators, water quality, SWAT modelling, nutrient management (NuMaSS), desertification processes, and field monitoring systems on land degradation. Eight soil-plant-water laboratories from Guatemala, Honduras and Nicaragua made initial steps to develop a sub-network to foster quality control and information comparison/exchange on analytical procedures for nutrient management recommendations. Twelve field days were organized in Cauca and three training courses were organized in the Colombian Llanos.

Methodologies for farmer-to-farmer learning

Numerous projects have addressed the challenges of building farmers' capacity for improved soil fertility management. For example, the exchange of ISFM knowledge within farmer field school and farmer research groups in East Africa has been facilitated and studied in diverse settings, including with farmers' own evaluation of the learning process [29, 43, 112, 119, 406]. The "Payment for Environmental Services" project of the WFCP has used training courses held in the conservation agriculture pilot site in Fuquene and subsequent courses at the extrapolation sites to build skills and capacity in farmer groups and partner organizations (development agencies, NGOs). Finally, in developing the guide for integrating local and technical indicators of soil quality, Latin American and East African universities, NGOs, and local communities participated in the process, exchanging information and updating the knowledge base [93].

Challenges and new opportunities

- Restructuring AfNet under the umbrella of the Forum for Agricultural Research in Africa (FARA), managed by TSBF-CIAT, to accommodate the growing membership. Multidisciplinary, regional research teams will coordinate and facilitate research in three regions (East Africa, West and Central Africa and Southern Africa). Interdisciplinary country-level proposals will be developed to further strengthen the country and regional teams.

- MIS is concentrating on developing proposals where the role of the Consortium as the key component for capacity building could be sold (e.g. Quesungual Agroforestry System and NuMaSS projects). Partners are now leading the consortium (e.g. the Executive committee is now driven by experienced researchers from Honduras and Nicaragua).

- Institutionalizing capacity in universities and other training institutions. AfNet members in selected universities will develop and implement curricula on soil biology and fertility.

- Implementing the "T-shaped skills" approach to capacity building (specialization within a context of broad multidisciplinary ability), using multi-disciplinary and participatory research approaches, increased integration of training with field experiments/practice ("Learning by doing"), with follow-up activities after training to assess impact.

- The networks will play a major role in the advocacy of the problem of soil fertility depletion and the role policy makers need to play to redress the situation.

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Annex 1. Recommendations from the Center Commissioned External Review (CCER) and CIAT response

Four simultaneous separate but parallel CCER of CIAT were conducted during the period 8-19 May 2006. Three review panels assessed the three major program areas of CIAT, its Research for Development Challenges (RDCs): Sharing the Benefits of Agrobiodiversity, Enabling Rural Innovation and Improving Management of Agro-ecosystems in the Tropics (IMAT). In addition there was a fourth CCER panel on management and governance.

TSBF-CIAT (PE-2 Project) belongs to the IMAT-RDC that was reviewed by a team composed of the following experts:

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Enrique Torres	Associate Professor (retired), Plant Pathology Universidad Nacional de Colombia, Bogotá, Colombia. E-mail: etorrest@mixmail.com

With few exceptions, the panels found the quality of the staff and of the research at CIAT to be high. The major substantive recommendations were: to more tightly focus the research program; to attain greater integration of that program; and to improve lines of authority and responsibility. Below are the specific recommendations made by the review team and responses by TSBF-CIAT staff.

1. TSBF should continue its major role in the Conservation and Sustainable Management of Below-ground Biodiversity (CSM-BGBD) project, but concentrate on the functional interpretation of below-ground biodiversity and attempt to link it to concepts that are used in ISFM as well as IPM.

Agreed. The CSM-BGBD project has just completed an inventory of below-ground biodiversity in seven tropical countries (India, Indonesia, Uganda, Kenya, Côte d'Ivoire, Mexico and Brazil) with diverse ecosystems and agricultural production environments. The second phase of the project will emphasize more on how below-ground biodiversity functions benefit farmers such as use in pest and disease control, use for soil and crop productivity improvement (i.e. nitrogen-fixation, crop-root extension, availability of phosphorous, soil structure improvement, composting and soil organic matter humification) thus contributing to the ISFM paradigm and also contributing to ecosystem and environmental services such as improving soil water infiltration and filtration, regulation of greenhouse gas emissions and carbon sequestration. Formal partnerships are established within TSBF-CIAT and AfNet on ISFM and Crop and Agroecosystem Health Management project on IPM.

2. Further strengthen research in TSBF on practical strategies and decision support tools for integrated water and nutrient management, including organic and mineral nutrient sources. Add such components to the existing organic resources DSS/database and include social science aspects in the decision-making process and tools to better understand actionable management strategies, their knowledge requirements, and economics.

Agreed. At the moment, TSBF is undertaking research to address the water and nutrient issues within the newly funded project from SDC-Switzerland under the Water and Food Challenge Program (WFCP). Efforts for the next 3 years will be intensified to build the capacity of TSBF and its partners in the application of decision support tools. Linkages with the BP2 Decision Support Project of CIAT could be an important resource. Efforts are being made to build the capacity of TSBF-CIAT and its collaborators in the application of decision support tools including the role of water in the interaction between the organic and inorganic inputs on crop productivity especially in semi-arid areas in sub-Saharan Africa (SSA).

3. Improve linkages with the private sector to improve access to fertilizer and develop recommendations for its use that are of mutual benefit to all stakeholders involved. TSBF should become the lead institution for providing scientific information to the industry on realistic markets. These will incorporate: data on soils and cropping systems, optimal fertilizer formulations for balanced crop nutrition, fertilizer packaging and information content provided to farmers, practical ISFM concepts, the decision support tools needed for their implementation, and socio-economic research on needs for fertilizer marketing infrastructure, integration with local knowledge to enhance adoption, economic benefits for farmers, and societal costs as a whole.

Largely agreed. Important aspects of this recommendation are being implemented. TSBF-CIAT is playing a key role in the implementation of the recommendations of the African Fertilizer Summit taking specific action to improve farmer access to fertilizer, quality seeds, extension services, market information and soil nutrient testing and mapping to facilitate effective use of inorganic and organic fertilizers, while paying attention to the environment. New projects have been designed to:

a) Adapt profitable fertilizer technologies to farmers biophysical and socio-economic environments.

b) Analyze current market opportunities and information systems and test alternative options to effectively link farmers to inputs, financial and outputs markets.

c) Strengthen capacity of farmers, researchers, extensions agents, agro-dealers and NGO's and local institutions on fertilizer use and village level market development.

d) Develop tools for scaling up and a framework for the extrapolation of results.

e) A major project on the role of fertilizer on the environment in SSA is being discussed favorably with GEF-UNEP.

TSBF-CIAT is already enhancing the access of farmers to fertilizers in many of its ongoing projects. An example is the soybean project (through a strategic alliance of all stakeholders including fertilizer dealers). With respect to the provision of scientific information to the fertilizer and other farm input industry and to complement the activities of biophysical scientists in generating and fine-tuning fertilizer recommendations in line with the socio-economic and cultural realities of the smallholder farmers, TSBF-CIAT recently completed a study on farm and agro-inputs (including fertilizers) in 40 markets in Western Kenya and plans to carry out a similar study in Uganda, Malawi and Tanzania in the near future. TSBF-CIAT is closely working with private sector dealing with fertilizers through strong NGOs such as Citizens Network for Foreign Affairs (CNFA) and IFDC. That said, aspiring to the leading position as provider of market information to the fertilizer industry is not likely to be a feasible or desirable goal for TSBF.

4. Place less priority on soil quality research in TSBF-CIAT that has no clear linkage with ISFM. Understanding and classifying soils based on "soft" local knowledge and generalizing this knowledge in simple farm-level DST is likely to be of greater impact for improving nutrient management at the farm level.

Seek collaboration with BP-2 on developing a joint digital soil mapping project for the SSA region, which could include non-destructive soil measurement methods such as VNIR-DRS.

Agreed. TSBF-CIAT soil research is based on the ISFM model and the in-built concepts and integrates local communities and their 'real worlds'. In this regard, TSBF will continue to simplify soil classification in terminologies and farming aspects that farmers easily identify with. TSBF-CIAT is already assembling soil characteristics spatial datasets, spatial climatic datasets, spatial altitude datasets in East Africa with emphasis to Kenya with a view to combining the datasets to aid in decision support for areas most suitable for soybean cultivation in Kenya. These datasets are available and will be shared with BP-2 and other CIAT projects to aid in decision making for other crops and germplasm and for formulating research agenda. TSBF-CIAT in collaboration with ICRAF is already having projects that are going to use VNIR-DRS spectroscopy in soil characteristics mapping and developing markers for other soil attributes that are not yet characterized to aid TSBF-CIAT in technology up-scaling and out-scaling.

5. TSBF-Africa should gradually scale-up its research to farm and landscape levels. Farm level is likely to be the key scale for intervention. TSBF should attempt to generalize the findings from its research on farm level gradients in soil fertility into generic rules and tools that can be used in guiding ISFM in practice. Landscape level studies are primarily of interest for assessing community interactions, environmental and social impact of new land use or management practices such as ISFM. TSBF should cautiously move towards this by conducting one or two carefully designed, integrated studies in collaboration with other CIAT scientists (PE-3, BP-2, ERI).

Agreed. Yes indeed there are already lessons learnt from the soil fertility gradient research in TSBF-CIAT with results that have generic attributes that can aid in formulating cropping generic decision rules that can be applied to new areas with minimal validation as inputs to the ISFM approach. Further on this, work by TSBF-CIAT at the farm and the landscape levels have already been initiated in new project proposals one to SSA Challenge Program for the lake Kivu pilot learning site including Rwanda, Uganda and East DRC. Plans to scale up results of this pilot learning site to the other two sites (i.e. in West Africa and Southern Africa) are being discussed with FARA. The other project is with WFCP in which collective action on watersheds and larger landscapes are emphasized. Collaboration with PE-3, BP-2 and ERI will strengthen the understanding of landscape level interactions that will aid in the development of most appropriate impact pathways for land use decisions as well as for quantifying the impact magnitudes.

6. Continue research and development work on linking farmers to markets, nutrition and health, but establish a more coherent strategy for this along fewer, major themes. Work on promiscuous soybean as part of ISFM. A well-defined portfolio of higher-value crops for niche markets should have priority. Ensure good integration with other CIAT projects.

Agreed. We agree on the need for a more coherent strategy (along fewer major themes and well-defined portfolio of higher-value crops for niche markets) in linking farmers to markets, nutrition and health in our research and development work. TSBF-CIAT is currently developing some new proposals to strengthen its work on high value crops, including the presently underutilized ones. A concept note (CN) on this subject will be submitted to respond to the recent call for CN by the Bill and Melinda Gates Foundation. Along with the high-value crops that TSBF-CIAT is currently working on, these will be re-assessed, prioritized and properly integrated with the higher-value crops that are being developed under the other CIAT projects. The work on promiscuous soybean is currently being carried out as a part of ISFM and will be strengthened to ensure that no element is neglected. However, emphasis on high value crops may not meet the needs of all African farmers in all growing and market environments so work on food staples will remain part of the overall effort.

7. Social scientists working in or with TSBF can make major contributions to improving NRM research, particularly ISFM. They should be integrated in the complete project development and implementation cycle, but their work should also not become detached from the TSBF core objectives. For full integration of social sciences in TSBF both biophysical and social scientists must define and focus on common themes of mutual interest that serve farmers and other rural people, contribute to ecosystem health, and inform policy makers, the public, and the scientific community (across disciplines).

Agreed. Social science research has been in the process of being integrated into the project development cycle. Greater efforts are being made to clarify common themes of mutual interest between biophysical and social scientists, with emphasis on integrating the work of CIAT's Enabling Rural Innovation team in Africa more closely with TSBF-CIAT. The joint project by TSBF-CIAT and ERI funded by IDRC on institutionalizing participatory research in AfNet illustrate well the collaborative effort between the biophysical and socio-economist scientists.

8. To address the potential adoption and impacts of mineral fertilizers in ISFM and in rural livelihoods and farming communities more broadly, we highly recommend the exploration of social network analysis and models beyond the social capital paradigm.

Agreed. Social networks are important ingredients for adoption of technologies since they are based on who the farmers trust most during technology diffusion and uptake. Studying social networks will complement the social capital paradigm to aid in understanding what drives the farmer's decisions and action during technology adoption. Social network analysis and models need to be explored beyond the social capital paradigm and include critical issues such as the impact of cultural and social typologies on participation in research and development, technology design and evaluation, access to information and technology adoption and the impact of agricultural technologies and delivery methods on different social groups.

9. TSBF social scientists need to evaluate the impact of cultural and social differentiation on potential markets and product supply chains as well as on processes of information exchange and terms of participation in research, technology design, and interventions and evaluation. Likewise, the reverse is true, researchers should attempt to predict and respond to the differential impact of specific technologies and delivery strategies on distinct social groups by gender, class, age, health status (including incidence of HIV and AIDS).

Agreed. Selected case studies on the relation between socio-economic differentiation and potential ISFM innovations will be undertaken in the context of a market chain perspective. This work will be done with partners, including research groups at CIAT. The results of these studies should provide guidance to the design of new ISFM options targeted to the particular circumstances of different social groups so that the benefits of ISFM innovations reach a wider set of potential users and beneficiaries.

10. CIAT needs to ensure that its current commitments to the MIS network are honored until completion, including collaborative research such as the SANRM-CRSP project funded by USAID. This is important for sustaining donor creditability.

Agreed. CIAT plans to honor the current commitments to the MIS network through two special projects: one on Nutrient management (Validation of NuMaSS decision support system) funded by USAID-SANRM-CRSP and the other on Quesungual system funded by CPWF.

11. Maintain a basic level of soil science expertise at CIAT-HQ to support the new integrated project PE-3 (at least one senior scientist), with emphasis on soil conservation and soil-water relations for improving nutrient use efficiency. Concentrate the work of CIAT's senior plant nutritionist/plant physiologist on support for germplasm improvement programs, with

emphasis on improving crop adaptation to soil acidity and other abiotic stresses.

Agreed. CIAT intends to maintain a small Latin American soils research capacity supported mostly with regional funding sources while attempting to reinvigorate this line of research with a view to tapping funds to expand this work in the future.

12. Through collaborative research, strengthen the scientific capacities in plant nutrition research in support of the large activities on Integrated Soil Fertility Management in Africa, with emphasis on understanding crop nutrient requirements, congruence of nutrient demand and nutrient supply, interactions between nutrients and water, and impacts on nutritional quality of food products.

Agreed. A Post-Doctoral scientist with expertise in plant nutrition with emphasis on ISFM has been recruited to address the above issue. He will be supported by the Senior Plant Nutritionist from the CIAT-HQ with the strong collaboration from the Department of Plant Nutrition and Soil Science of the Catholic University of Leuven, Belgium. The scientific capacity building of our collaborators through the African Network for Soil Biology and Fertility (AfNet) remains high priority for TSBF. There are a number of ongoing plant nutrition and ISFM oriented research activities in many sites that are being implemented by AfNet members. Most of these activities are supported by periodic capacity building efforts on participatory research and scaling up, gender analysis, nutrient monitoring (NUTMON), Decision Support Systems for Agrotechnology Transfer (DSSAT), and agroenterprise development.

13. TSBF-Africa should cautiously expand its activities in SSA, with initial emphasis on establishing and strengthening regional hubs in Southern and Central Africa and few agro-ecosystems of major importance. Expansion into West Africa could follow, but must always be seen within the context of potential overlap with activities conducted by other organizations such as IITA and IFDC. Research in Latin America should concentrate on fewer key locations that are important for plant nutrition/germplasm improvement and soil conservation and ISFM within a watershed context, along the lines of the structural changes proposed. TSBF-Africa should continue to strengthen its collaboration with other CIAT projects that primarily operate in Latin America and particularly gain from their expertise in adapted germplasm, soil conservation and land use analysis at watershed levels.

Agreed. Regional hubs in Southern and Central Africa and few agro-ecosystems of major importance are well established and very functional. At the moment, the expansion in West Africa is only through the AfNet members and other activities undertaken in West Africa are in full integration with work by ICRISAT, IITA and

IFDC. As indicated in response to recommendation 27, CIAT intends to maintain a small capacity in soils research in Latin America to contribute to the People and Agroecosystems RDC (research for development challenge) activities at a few key locations within a watershed context. TSBF Africa intends to strengthen its efforts on crop-livestock systems by integrating new crop and forage options based on the successful efforts made in Latin American hillsides and savanna agro-ecosystems. Recently developed Brachiaria hybrids that are adapted to low soil fertility and drought, and improved common bean and cassava germplasm could form an integral part of this strategy. Soil conservation and land use analysis are the two key components of Agro-ecosystem Management at watershed level. TSBF-CIAT will further strengthen its collaborative research efforts with other elements of the CIAT People and Agroecosystems RDC with which it will share a common research paradigm.

14. CIAT needs to ensure that the administrative support systems allow TSBF to operate as an institute. Likewise, we recommend the inclusion of the CIAT Regional Coordinator for Africa as an ex oficio participant in the annual scientist evaluation and project development process so that he/she is fully informed and can contribute to team development, as well as linkages with other CIAT programs and potential donors. The Regional Coordinator should not have a staff evaluation authority for TSBF scientists.

Partly agreed. There has been for some time an established exchange of visit from the administrative staff of CIAT-HQ to improve the financial management of TSBF-CIAT in Nairobi and the TSBF-CIAT administration staff periodically visit CIAT-HQ to familiarize with administrative and financial issues. There is an ongoing daily exchange of financial information through electronic means. Nonetheless, considerable effort remains to be made to further improve these systems. As for information exchange with the Regional Coordinator for Africa, besides ongoing information between the RCA and the Director of TSBF, there is also an annual joint meeting between CIAT Africa and TSBF-CIAT to coordinate implementation of joint projects. There are ongoing joint projects and new projects are being developed to integrate both CIAT and TSBF-CIAT research portfolios. Reporting relations are reviewed annually and will be modified as needed.

15. Decision Support Tools are an important component of crop, soil fertility and nutrient management research and extension. TSBF should ensure that some of its strategic research includes high-quality field studies and data collection that would allow to validate and further improve process-based DST such as crop simulation or more complete agroe-cosystem simulation models. Understanding of prediction uncertainties must be a key component of such research.

Agreed. TSBF-CIAT has many collaborating scientists in the CSM-BGBD project as well as in the AfNet project that are continuously collecting data on soils, crops, environment, species and other success determinant attributes that can aid in decision making. TSBF-CIAT will further dedicate its efforts in strengthening the existing databases and extend their use as DST in simulation modeling, risk modeling and for highlighting the productivity uncertainties so as to raise the success 'hit-rates' with all the technologies they produce. Training courses on DSSAT are a valuable contribution to the understanding of the processes that determine crop responses and also predict crop performance and resource use.

Table 1. Scientific performance by four projects (PE-1, PE-2, PE-3 and PE-4) within IMAT-RDC. Values shown are annual averages for the period 2002 to 2005. PE-1 = Crop and agroecosystem health management; PE-2 = TSBF-CIAT (Integrated soil fertility management in the tropics); PE-3 = Communities and watersheds; BP-2 = Spatial and economic analysis for policy and decision support in agriculture and environment.

Inputs/outputs/indicators		PE-1*	PE-2	PE-3	BP-2
Inputs					
FTE senior scientists (SS)	FTE/yr	1.96	8.25	5.25	4.53
FTE senior research fellows (SRF)	FTE/yr	0.93	4.25	0	2.68
FTE visiting scientists (VS)	FTE/yr	1.00	0	0	0
FTE PostDocs (PDF)	FTE/yr	0	2.25	0.25	0.64
Total funding	$/yr	1,652,734	6,296,696	1,039,798	2,179,250
Unrestricted core funding	$/yr	209,506	1,059,300	616,775	1,103,000
Restricted core funding	$/yr	44,899	161,417	0	173,250
Special projects and CP funding	$/yr	1,398,329	5,075,980	423,023	903,000
Outputs					
No. of PhD students completed	no./yr	4.8	5.3	0	1.3
No. of MSc students completed	no./yr	8.8	11.0	1.5	2.0
No. of BSc students completed	no./yr	15.3	6.3	2.0	2.0
No. of refereed journal papers	no./yr	42	21	6	10
No. of refereed book chapters	no./yr	7	8	4	3
Other intellectual important products	no./yr	3		2	1
Performance indicators					
Total senior staff time in project (SS, SRF, VS)	FTE/yr	3.89	12.50	5.25	7.20
Total funding per senior staff FTE	$/FTE/yr	425,141	503,736	245,033	322,190
Unrestricted core funding per senior staff FTE	$/FTE/yr	53,892	84,744	140,244	156,691
Grant funding per senior staff FTE	$/FTE/yr	371,248	418,992	104,789	165,498
% grant funding of total funding per FTE	%	87	83	43	51
Graduate students per senior staff FTE	no./FTE/yr	3.5*	1.3	0.5	0.5
Undergraduate students per senior staff FTE	no./FTE/yr	3.9*	0.5	0.5	0.3
Refereed journal publications per FTE senior staff	no./FTE/yr	10.9*	1.7	1.1	1.4
Senior staff journal publications track record	no./yr	1.7	2.9	0.6	1.1

Explanations

- FTE = full time equivalent (person-years).
- Senior staff time FTE = SS + SRF + VS time allocations to the each project.
- Grant funding per senior staff FTE = includes restricted core, special projects and Challenge Programs.
- Refereed journal publications per FTE senior staff = all journal articles published from the project (numbers provided by projects).
- Senior staff journal publications track record = based on all refereed journal papers published by each SS, SRF or VS during 2002-2005/6 (derived from CVs provided; only includes SS, SRF and VS with more than 2 years work in the project, also counting papers they have published from other work outside the projects reviewed here).

* PE-1 = numbers are not fully correct because outputs from five SS with voluntary participation in PE-1 are included, whereas those SS have no official resources (inputs) allocated. A pro-forma FTE of 0.3/yr was included for this in the analysis, but this does not reflect the true contributions and still results in inflated estimates of students/FTE/yr and publications/FTE/yr. Senior staff journal publication track record is a better measure of scientific quality and directly comparable with the other projects.

Table 2. Scientific performance indicators of Project PE-2 (total of TSBF Africa and TSBF Latin America, includes previous SWNM project that has now become part of TSBF) from 2002 to 2005.

Indicators	2002	2003	2004	2005
FTE senior scientists (person-years)	6.7	7.7	8	8.8
FTE PostDocs (person-years)	6.0	8	6	9.2
Total no. of PhD students completed	1	5	17	4
Total no. of MSc students completed	1	9	35	15
Total no. of BSc students completed	1	8	2	13
Total unrestricted core funding ($)	987,142	917,341	1,267,200	1,592,246
Total external grant funding ($)	3,265,313	6,770,371	5,285,830	4,230,855
Total no. of refereed journal papers	17	27	16	25
Total no. of refereed book chapters	3	10	15	3

Annex 2. TSBF-CIAT's staff list

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TSBF Institute – Africa Staff

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Jonas Chianu (Socio-economist)
Robert Delve (Soil Fertility Management)
Jeroen Huising (BGBD Coordinator/ GIS Scientist)
Joyce Jefwa (Microbiologist)
Didier Lesueur (Microbiologist)
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Pieter Pypers (Plant Nutritionist)
Joshua Ramisch (Social Scientist)
Kristina Roing (Agronomist)
Bernard Vanlauwe (Soil Scientist)
Ritu Verma (Anthropologist)
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Mike Swift (BGBD Project)

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Caren Akech (Secretary)
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Stephen Chisvino (Driver/OA, Harare)
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Rosemary Meyo (Administrative Assistant)
Caleb Mulogoli (Finance/IT Asst)
Charles Ngutu (Finance/Admin. Officer)

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Juliet Ogola (Senior Administrative Secretary)

TSBF Institute – Latin America Staff

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Miguel Ayarza (Agronomy), MIS Coordinator, Honduras
Edmundo Barrios (Soil Ecology and Biodiversity)
Rubén Estrada (Resource Economist, CIP)
Idupulapati Rao (Plant Nutrition and Physiology) (40% TSBF Institute, 30% IP-1 (Beans), 30% IP-5 (Tropical Forages)

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Acronyms and Abbreviations

AfNet	African Network for Soil Biology and Fertility
AHI	African Highlands Initiative
AMF	arbuscular mycorrhizal fungi
APSIM	Agricultural Production Systems simulator
ARIs	Advanced Research Institutes
BG	below-ground
BGBD	below-ground biodiversity
BNF	biological nitrogen fixation
CAFTA	Central America Free Trade Agreement
CCER	Center Commissioned External Review
CEC	cation exchange capacity
CGIAR	Consultative Group on International Agricultural Research
CN	concept note
CNFA	Citizens Network for Foreign Affairs
CONDESAN	Consorcio para el Desarrollo Sostenible de la Ecorregión Andina (*Consortium for Sustainable Development in the Andean Ecoregion*)
CORPOICA	Corporación Colombiana de Investigación Agropecuaria (*Colombian Corporation for Agricultural Research*)
CSM-BGBD	Conservation and Sustainable Management of Below-Ground Biodiversity
DSSAT	Decision Support Systems for Agrotechnology Transfer
DST	Decision Support Tools
ERI	Enabling Rural Innovation
FARA	Forum for Agricultural Research in Africa
FRC	farmer research committees
GDP	gross domestic product
GEF-UNEP	Global Environment Facility/United Nations Environment Programme
GHG	green house gas
HVC	high value crops
IAEA	International Atomic Energy Agency, Austria
ICRAF	World Agroforestry Centre, Kenya
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics, India
IDRC	International Development Research Centre, Canada
IFDC	International Center for Soil Fertility and Agricultural Development, USA

IFS	International Foundation for Science, Sweden
IITA	International Institute of Tropical Agriculture, Nigeria
IMAT-RDC	improving management of agro-ecosystems in the tropics-research for development challenge
INM	integrated nutrient management
IPG	International public goods
IPM	integrated pest management
ISFM	Integrated Soil Fertility Management
IVDMD	*In Vitro* Dry Matter Digestibility
MICROBES	Microbial Observatories for the Management of Soil Ecosystem Services in the Tropics
MIS	Manejo Integrado de Suelos (*Integrated Soil Management Consortium*)
NARES	National agricultural research and extension services
NGOs	nongovernmental organizations
NIRS	near infrared reflectance spectroscopy
NRM	natural resource management
NUANCES	Nutrient Use in Animal and Cropping systems-Efficiencies and Scales
NuMaSS	nutrient management support system
NUTMON	nutrient monitoring
POM	particulate organic matter
QSMAS	Quesungual Slash and Mulch Agroforestry System
R4D	research for development
RDC	research for development challenge
R-to-C	Resource to Consumption
SARNet	South Asian Regional Network
SDC	Swiss Agency for Development and Cooperation
SLM	sustainable land management
SOM	soil organic matter
SSA	sub-Saharan Africa
TLC	Free Trade Agreement
USAID-SANRM-CRSP	United States Agency for International Development-Sustainable Agriculture and Natural Resource Management-Collaborative Research Support Programs
VNIR-DRS	Visible-Near Infrared Diffuse Reflectance Spectroscopy
WHC	water holding capacity
WOTRO	Stichting Wetenschappelijk Onderzoek in the Tropen (*Netherlands Foundation for the Advancement of Tropical Research*)
WFCP	Water and Food Challenge Program

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