Eco-friendly Management of PHYTONEMATODES

Indra Rajvanshi
Girdhari Lal Sharma

Eco-friendly Management of Phytonematodes

"This page is Intentionally Left Blank"

Eco-friendly Management of Phytonematodes

Editors
Indra Rajvasnshi
G.L. Sharma

Oxford Book Company
Jaipur , India

ISBN : 978-81-89473-00-6

First Published 2007

Oxford Book Company
267, 10-B-Scheme, Opp. Narayan Niwas,
Gopalpura By Pass Road, Jaipur-302018
Phone: 0141-2594705, Fax: 0141-2597527
e-mail: oxfordbook@sify.com
website: www.abdpublisher.com

Typeset by :
Shivangi Computers
267, 10-B-Scheme, Opp. Narayan Niwas,
Gopalpura By Pass Road, Jaipur-302018

Printed at :
Rajdhani Printers, Delhi

Preface

The population of India is out breaking and already crossed above 100 crores which has created a great imbalance for the food supply to the people. The damage caused by various pests to the field crops reaches nearly up to 45.0 per cent. Our annual crop loss of 30 to 40 million tonnes can be prevented by adopting effective crop protection measures. According to 1984 FAO estimates, the plant parasitic nematodes cause 12.3 per cent yield loss of world's major crops, which amounts worth of Rs. 50 billion. The management of crop production constraints increases chances of insulating the world's population from hunger. The phytonematodes being microscopic in size behave as hidden enemies producing no spectacular symptoms unlike insects, therefore, their management receives less attention by the growers.

In the developing countries nematicides like other chemical pesticides have been under pressure, time and again due to associated problem of residual toxicity, environmental pollution and public health hazards. Among the several alternative strategies implemented so far, the use of integrated nematode management proved to be economic and environmentally safe tool for reducing the economic losses in the field crops as well as to lower down the nemic population below the disease threshold level. The research efforts for generating INM modules for each crop basis is a today's need for getting better crop yield. The ultimate aim of the nematologist is to evolve effective INM programme to reduce the phytonemic incidences, to increase the crop production, to safe the environment of surrounding ecosystem and finally to learn, teach and trained the entrepreneurs and growers.

This book entitled "Ecofriendly Management of Phytonematodes" includes detailed compilation of various phytonematodes management strategies in field crops like cereals, bast fibre crops, maize, pulses, sugarcane, tobacco, vegetables and medicinal and aromatic plants along with the role of nematodes in agro-ecosystem management and also about the nemic management by fungi as well as various cropping patterns sequences by various experienced authors.

Thus the book provides a good glimpse of the phytonematodes management.

We are grateful to all the learned contributors, who have included all detailed pertaining informations much related to the title of the book and also about their untiring work to compile it.

We are grateful to our hon'ble vice chancellor, RAU, Bikaner, for blessing and encouraging to publishing such an exhaustive compilation.

We also express our sincered gratitude to our working Director Research, RAU, Bikaner and Dean, SKN College of Agriculture, Jobner for constant encouragement and co-operation for publishing this book.

We express our gratitude to all our family members for extending their co-operation in many invisible ways to us. We also highly appreciate the all around co-operation and support of publisher for publishing this book with patience, care and interest.

Indra Rajvanshi
G.L. Sharma

List of Contributors

A.D. Patel

Department of Nematology, B.A. College of Agriculture, Anand Agricultural University, Anand-388 110

A.K. Ganguly

Division of Nematology, Indian Agricultural Research Institute, New Delhi-110 012

A.N. Srivastava

Division of Nematology, Indian Agricultural Research Institute, New Delhi-110 012

Akhtar Haseeb

Department of Plant Protection, Faculty of Agricultural Sciences, Aligarh Muslim University, Aligarh-202 002

Anil Kumar

Department of Nematology, CCS Haryana Agricultural University, Hisar-125 004

Anita Sharma

Department of Plant Protection, Faculty of Agricultural Sciences, Aligarh Muslim University, Aligarh-202 002

Anju Kamra

Nematology Section, Sugarcane Breeding Institute, Coimbatore, 641 007

Archna Mittal

Division of Nemotology, IARI, New Delhi-110 012

C.D. Mishra

Central Rice Research Institute, Cuttack-753 006, (Orissa)

D. Prasad

Division of Nematology, Indian Agricultural Research Institute, New Delhi-110 012

D.J. Patel

Department of Nematology, B.A. College of Agriculture, Anand Agricultural University, Anand-388 110

Dr. A.K. Singh

Senior Scientist (Nematology), Directorate of Wheat Research, Karnal-132 001

Dr. S.D. Mishra

Division of Nematology, Indian Agricultural Research Institute, New Delhi-110 012

G.L. Sharma

Department of Nematology, SKN College of Agriculture, Jobner, Jaipur-303 329

Gautam Chawla

Division of Nematology, Indian Agricultural Research Institute, New Delhi-110 012

Indra Rajvanshi

Department of Nematology, ARS, Durgapura, Jaipur-302 018

K.S. Krishna Prasad

Central Potato Research Station, Ootacamund-643 004, Nilgiris District

N. Somasekhar

Division of Nematology, Indian Agricultural Research Institute, New Delhi-110 012

R.K. Jain

Project Coordinator, AICRP (Nematodes), Div. of Nematology, ICAR, New Delhi-110 012

R.K. Walia

Department of Nematology, CCS Haryana Agricultural University, Hisar-125 004

R.S. Kanwar

Department of Nematology, CCS Haryana Agricultural University, Hisar-125 004

R.V. Vyas

Department of Nematology, B.A. College of Agriculture, Anand Agricultural University, Anand-388 110

Rakesh Pandey

Central Institute of Medicinal and Aromatic Plants (CIMAP-CSIR), P.O. CIMAP, Lucknow-226 015

Rashid Pervez

Division of Crop Protection, Indian Institute of Pules Research, Kanpur-208 024

S.K. Laha

Central Research Institute for Jute and Allied Fibres, Barrackpore, W.B.-743 101

S.S. Ali

Division of Crop Protection, Indian Institute of Pules Research, Kanpur-208 024

Usha K. Mehta

Emeritus Scientist, Department of Environmental Sciences, Bharathiar University, Coimbatore-641 046

Contents

"This page is Intentionally Left Blank"

1

Eco-friendly Management of Phytonematodes in Pulses

S. S. Ali and Rashid Pervez

Introduction

Nematodes are reported to be one of the biotic constraints in the production of pulse crops over 200 species of plant parasitic nematodes are reported as ectoparasitic, semi endoparasitic or migratory or sedentary endoparasitic of pulse crops. Plant parasitic nematodes are one of the important constraints in reducing both the quantity and quality of pulse crops. They are considered to be a hidden enemy of crops due to their microscopic size, hidden habitats and lacking in manifestation of clear-cut symptoms on the aerial parts of the plants. Among nematode diseases of pulse crops, root-knot disease is predominant and widespread throughout the pulse-growing regions of the country. Out of 13 species of root-knot nematode reported in India, only *Meloidogyne incognita* and *Meloidogyne javanica* are the causal agent of root-knot disease in pigeonpea, mungbean, urdbean, cowpea, chickpea, lentil, common bean, fieldpea and some of the minor pulses like lathyrus, horse gram and rice bean. Although a number of plant parasitic nematodes such as *Pratylenchus* spp., *Rotylenchulus* spp., *Heterodera* spp., *Tylenchorhynchus* spp., *Helicotylenchus* spp., *Hoplolaimus* spp. are also infesting pulse crops but they are considered less potential than root-knot nematodes. *M. incognita* and *M. javanica* are reported from chickpea and pigeonpea from 80 and 44 districts of the country respectively (Ali, 1995; Sharma *et al.*, 1993, 1996). The distribution of *Heterodera cajani* is widespread on pigeonpea and it is reported from 88 districts of the country (Sharma *et al.*, 1992a, 1993, 1996), while *H. swarupi* is reported on chickpea from 6 districts of Rajasthan. Another widely distributed nematodes both on chickpea and pigeonpea, *Rotylenchulus reniformis* and *Hoplolainus indicus* are reported from 55 and 80 districts respectively. *Pratylenchus thornei* is more abundant on chickpea than pigeonpea and is reported from 39 and 19 districts, respectively.

Occurrence and Distribution

Although nematodes occurs in pulses growing areas, the most severe damage occurs in warm regions into more number of generations per season, causing higher nematode populations. Occurrence of nematode species may vary from region to region. More than one nematode species may also occur simultaneously in the same region. The occurrence of a particular nematode may also depend upon the prevalent cropping system in the region (Table 1).

Table.1 List of plant parasitic nematodes associated with different pulse crops

Crops	Nematodes	
Chickpea	*Aphelenchoides* sp.	*H. oryzae*
	Aphelenchus sp.	*Hirschmanniella* spp.
	Basiria sp.	*Hoplolaimus* spp.
	Basirolaimus	*Longidorus* spp.
	B.dimorphicus	*Macroposthonia ornate*
	B .indicus	*Macroposthonia* spp.
	B. seinhorsti	*Malenchus* spp.
	Bitylenchus brevilineatus	*Meloidogyne arenaria*
	B. vulgaris	*M.incognita*
	Bitylenchus sp.	*M. incognita*
	Boleodorus sp.	*M. javanica*
	Carcharolaimus	*Merlinius brevidens*
	C. symmetricus	*Merlinius* sp.
	Criconema sp.	*Nothocriconemella* sp.
	Criconemella ornate	*Ottolenchus facultativus*
	Criconemoides sp.	*Paratylenchus mirzai*
	Detylenchus sp.	*Paratylenchus* spp.
	Helicotylenchus abunaamai	*P coffeae*
	H. dihystera	*P. mulchandi*
	H. indicus	*P. thornei*
	H. retusus	*P. zeae*
	H. sharafati	*Pseudhalenchus* sp.
	Helicotylenchus spp.	*Rotylenchulus reniformis*
	Heterodera cajani	*Rotylenchus* spp.
	H.mothi	*Scutellonema brachyurum*
	Heterodera spp.	*Scutellonema* spp.
	Hemicriconemoides cocophillius	*T. brassicae*
	Hemicrinemoides sp.	*T. elegans*
	Hirschmanniella mucronata	*T. mashhoodi*

		T. nudus *Tylenchorhynchus* spp. *Tylenchus* spp. *X. basiri* *Xiphinema* sp.
Pigeonpea	*Aphelenchoides aligarhiensis* *Aphelenchoides* sp. *Aphelenchus radicicolus* *Aphelenchus radicicola* *A. avenae* *Aphelenchus graminis* *Aphelenchus* spp. *Basiriolaimus seinhorstii* *B. indicus* *B. Columbus* *Basiria* spp. *Bitylenchus brevilineatus* *B. vulgaris* *Boleodorus* spp. *Carcholaimus bedizens* *C. symmetricus* *Criconema* sp. *Criconemella ornate* *Criconemoides* sp. *Ditylenchus* sp. *Ditylenchus archilisposomus* *Dolichorhynchus phaseoli* *Geocenamus brevidens* *Helicotylenchus abunaamai* *H. ciceri* *H. dihystera* *H. elegans* *H. indicus* *H. retusus* *H. maronatus* *H. sharafati* *Helicotylenchus* spp. *Hemicriconemoides cocophillus* *Hemicriconemoides* spp. *Heterodera avenae* *H. cajani*	*Longidorus* spp *Macroposthonia ornata* *Macroposthonia* spp. *Melenchus* spp. *Meloidogyne incognita* *M. javanica* *Meloidogyne* spp. *M. arenaria* *Merlinius brevidens* *Merlinius* spp. *Neoditylenchus* spp. *Nothocriconemella* sp. *Nothotylenchus* sp. *Nygolaimus harishi* *Ottolenchus facultativus* *Paraphlenchus amblyurus* *Paratrichodorus christiei* *Paratylenchus mirzai* *P. rotundicephalus* *Paratylenchus* spp. *Pratylenchus coffeae* *Pratylenchus indicus* *P. mulchandi* *P. thornei* *P. zeae* *Pratylenchus* spp. *Pseudhalenchus* spp. *Psilenchus* spp. *Rotylenchulus reniformis* *Rotylenchulus secundus* *Scutellonema erectum* *S. brachyurum* *Scutellonema* spp. *Siddiqia citri* *Telotylenchus crenatus* *Telotylenchus* spp.

	H. swarupi *H. mothi* *H. trifolii* *Heterodera* spp. *Hirshmanniella mucronata* *H. oryzae* *Hirshmanniella* spp. *Hoplolaimus dimorphicus* *H. indicus* *H. seinhorsti* *Hoplolaimus* spp *Longidorus pisi*	*Tylenchorhynchus* *T. elegans* *T. mashhoodi* T. brassicae *T. ciceri* *T.nudus* *T. sabourensis* *Tylechorhynchus* spp. *Tylenchus* spp. *Xiphinema lambertii* *X. basiri* *Xiphinema* spp.
Lentil	*Helicotylenchus abunaamai* *H. dihystera* *H. indicus* *H. retusus* *H. maronatus* *Helicotylenchus* spp. *Hemicriconemoides* spp. *Hoplolaimus* spp. *Meloidogyne incognita*	*M. javanica* *Merlinius* spp. *P. thornei* *Psilenchus* spp. *Rotylenchulus reniformis* *Scutellonema* spp. *T. elegans* *T. mashhoodi* *Tylenchus* spp.
Urdbean	*Helicotylenchus* spp. *H. cajani* *H. indicus* *Pseudhalenchus* spp. *Rotylenchulus reniformis*	*Telotylenchus* spp. *T. mashhoodi* *T. sabourensis* *Tylenchus* spp.
Fieldpea	*Aphelenchoides* sp. *Aphelenchus* spp. *Basiria* spp. *H. bihari* *Hemicriconemoides* spp. *Paratylenchus* spp.	*Rotylenchulus reniformis* *Rotylenchus* spp. *T. mashhoodi* *Tylenchus* spp. *Xiphinema* spp.
Lathyrus	*Basiria* spp. *Hemicriconemoides* spp. *Meloidogyne incognita*	*M. javanica* *Rotylenchulus reniformis* *Tylenchus* spp.
Rajmash	*Basiria* spp. *Hemicriconemoides* spp. *Meloidogyne incognita* *M. javanica*	*Rotylenchulus reniformis* *T. brassicae* *Tylenchus* spp

Nature of Damage/Symptoms

Nematodes cause root vascular and parenchyma disorders, suppress rhizobium nodulation and interact with several soil borne fungi. Plants express infestation in the form of drought stress, early senescence and poor yield. Tiyagi and Alam (1990) reported significant reduction in plant growth, water absorption and chlorophyll content due to *Meloidogyne incognita*, *Rotylenchulus reniformis* and *Tylenchorhynchus brassicae.* Chickpea inoculated with *M. incognita* and *M. javainca* showed significant reduction in shoot length, fresh shoot mass, number of pods/plant and grain yield (Manandhar and Amatya, 1990). *Meloidogyne incognita* also causes significant reduction in nodulation, nitrogenous activity of nodules and nitrate reductase activity of leaves in chickpea (Chahal and Chahal, 1991). The ectoparasitic nematodes *viz.*, *Hoplolaimus* spp., *Helicotylenchus* spp. and *Tylenchorhynchus* spp. are generally epidermal feeders and sometimes invade the cortical region of chickpea roots. The concomitant occurrence of *M. incognita* and *R.reniformis* causes stunting and reduction in root nodulation efficiency (Anver and Alam, 1997). A significant reduction was noticed when *M. incongnita* and *R. reniformis* were inoculated together (Zaidi *et al.*, 1988).

The presence of heavy population of root-knot larvae in the soil causes reduction in rhizobial nodulation due to reduction of root system and altered root physiology (Balasubramaniam, 1971). Beaded appearance of roots and root knot galls on root system is the most characteristic symptom of roots and root knot nematode infection, while symptoms of ectoparasitic nematodes appear dark brown to black lesion, injured root tips, malformed stubbiness, necrosis and stunting of roots. Field symptoms are manifested by patches of poor plant growth and wilted appearance from a distance. In severe infestation, patches become yellow. If wilt incidence occurs together with nematodes, first symptom is wilting followed by collapsing of seedlings here and there, and individual seedling exhibits yellowing of leaf tips, less branching and irregular leaf shape (Ali, 1995). At later stages, delayed flowering, chlorosis, yellowing of foliage and dropping of flowers are observed in case of severe infestation. Such plants show early senescence and produce deformed and smaller grains. Nematode infested plants are reported to bear seeds with reduced protein content (Greco and Sharma, 1990).

Crop Losses

Information on relationship between population densities of root-knot nematodes and yield losses reveals that *Meloidogyne* spp. are one of the major limiting factors to pulse production in India (Table 2). A report on global basis reveals that plant parasitic nematodes cause 13.7% yield loss in chickpea (Sharma and McDonald, 1990). Pot

culture experiments in chickpea suggested that two juveniles of *M. incognita* per 10 g of soil were required to cause substantial damage (Nath *et al.*, 1979), while *M. javanica* reduced plant growth at one juvenile per g of soil. The effect of *Heterodera cajani* was studied on pigeonpea variety ICP 6 under field condition and it was found that reduction in grain yield was 30.1% (Saxena and Reddy, 1987).

Table 2. Yield losses in pulse crops due to nematode pest

Crop	Nematode	Yield loss (%)	State	Reference(s)
Chickpea	*Meloidogyne incognita*	40.2	Maharashtra	Ali (1995)
		55.0	Gujarat	-do-
		42.8	Uttar Pradesh	-do-
		60.0	Rajasthan	-do-
	M. javanica	84.0	Haryana	-do-
		27.5	Uttar Pradesh	-do-
		9.2	Haryana	-do-
Pigeonpea	*M. incognita*	29.4	Maharashtra	Ali (1987)
	M. javanica	14.2	Gujarat	Sharma *et al.* (1993)
		19.2	Uttar Pradesh	Sharma *et al.* (1996)
Mung bean	*M. incognita*	33.9	Maharashtra	Ali (1997)
		11.36	Uttar Pradesh	Ali (1994)
		39.0	Rajasthan	Handa and Mishra (1989)
		34.5		
	M. javanica	14-29.0	Gujarat	Ali (1997)
	M.incognita+Rotylenchulus reniformis	49.6	Uttar Pradesh	Sharma *et al.* (1986)
			Madhya Pradesh	Ali (1995)
Urd bean	*M. incognita*	49.2	Gujarat	Ali (1995)
	M. javanica	29.0	Uttar Pradesh	-do-
	M. javanica+R. reniformis	41.5	Madhya Pradesh	-do-
Fieldpea	*M. javanica*	15.2	Uttar Pradesh	Ali (1992)
Lentil	*M. javanica*	15.4	Uttar Pradesh	-do-
Common bean	*M. incognita*	36-43	Karnataka	Ali (1997)
			Madhya Pradesh	Ali (1992)
	M. javanica	37.0	Uttar Pradesh	-do-

In pigeonpea cv. ICP 6 the reduction in plant growth and grain yield were 27.6% and 30.1% respectively due to cyst nematode *Heterodera cajani* (Saxena and Reddy,

1987). Under All India Coordinated Research Project on Improvement of Pulses a number of field trials were conducted to know the yield losses of pigeonpea due to nematode pest in different agro-ecological situations in the country. The yield loss of pigeonpea depends upon genotype, soil texture and type of nematode involved.

Globally, nematodes are responsible to cause 13.7% losses in chickpea (Sharma and McDonald, 1990). Recent estimate of global losses caused by plant parasitic nematodes is put to US $ 328 million annually to chickpea (Sharma *et al.*, 1992). The root-knot nematode (*M. incognita* and *M. javanica)* and *Pratylenchus thornei* have been reported to cause 19-40% and 26% economic loss, respectively. Ali (1997) reported 22-84% avoidable loss due to *M. javanica* and 25-60% due to *M. incognita.* He reported 11-18% yield loss due to *Rotylenchulus reniformis* and 25-30% due to *Pratylenchus thornei.* Another species of root-knot nematodes *M. arenaria* caused 39% loss in grain yield of chickpea in Gujarat (Patel, 1997). Mhase *et al.* (1997) estimated 42% yield loss due to root-knot nematode in Maharashtra. Information gathered from different sources on avoidable yield loss due to root-knot nematode in chickpea indicated 17-60% losses in Bihar, 17-56% in Gujarat, 8% in Haryana, 35-43% in Maharashtra, 22% in Punjab, 17-60% in Rajasthan and 22-23% in Uttar Pradesh. It is 12-24% due to *Pratylenchus thornei* and 11% due to *Rotylenchulus reniformis* in Madhya Pradesh.

Hot Spots

On the basis of survey in various parts of India, it has been found that root-knot nematodes (*M. incognita* and *M. javanica*) are the serious pest of pulse crops in most parts of the country. The major pulse crops, *i.e.*, chickpea, pigeonpea and mung bean are affected by these nematodes in Uttar Pradesh, Rajasthan, Haryana, Maharashtra, Gujarat, Madhya Pradesh and Bihar. Next to root-knot nematode, chickpea crops are attacked by lesion nematodes. Heavy infestation of root-knot nematodes on chickpea are reported in Mainpuri, Aligarh and Kanpur districts of Uttar Pradesh; Alwar, Jaipur and Ajmer districts of Rajasthan; Ludhiana in Punjab; Hisar in Haryana; and Rahuri in Maharashtra (Ali, 1995) while hot spots of lesion nematodes infesting chickpea are reported from Jabalpur and Hoshangabad districts of Madhya Pradesh and Sriganganagar, Bikaner and Ajmer districts of Rajasthan. Likewise hot spots of *H. cajani* infesting pigeonpea are Bharuch and Vadodra districts of Gujarat; Allahabad, Gonda, Faizabad, Meerut and Agra districts of Uttar Pradesh; Raichur, Bijapur and Dharwad districts of Kranataka; Jalgaon district of Maharashtra; Muzaffarpur district of Bihar; Medek district of Andhra Pradesh and Tiruchirapalli in Tamil Nadu. Hot spots of root-knot nematode infesting chickpea are Mainpuri, Aligarh, Gorakhpur and Gonda districts of Uttar Pradesh; Kheda district of Gujarat; Gwalior in Madhya Pradesh; Samastipur in Bihar; and Hisar and Rohtak districts

of Haryana (Ali, 1995). Nematode is considered a hot spot for both pigeonpea and chickpea in Vidarbha region of Maharashtra (Varaprasad *et al.*, 1997).

Host Range and Threshold Level

H. cajani has a wide host range, attacking most of the leguminous crops and some members of the Pedaliaceae family. *H. cajani* was recorded on early, medium and late maturing group of pigeonpea genotypes. In Tamil Nadu 1-19 cyst/200 cm^3 of soil was recorded from pigeonpea (Singh and Gill, 1989) while in Uttar Pradesh, Maharashtra, the population was cyst/200 cc soil in Karnataka and Bihar (Ali, 1991). In Gujarat average population was found 2 cysts/200 cc of soil. In ICRISAT fields, the population of *H. cajani* was found 158 cysts/500 cc soil in wet soil (black soil) particularly in the wilt (*Fusarium udum*) nursery in which pigeonpea had been cultivated every year for the last 10 years (Sharma, 1985). In eastern Uttar Pradesh in a random survey 60% of the cysts of *H. cajani* was found empty (Ganguly and Khan, 1989). A survey of *H. cajani* in pigeonpea fields in Varanasi, Uttar Pradesh from October 1970 to April 1971 showed that the cyst population was lowest in January when soil temperatures were low and high in April when soil temperatures has increased (Singh and Rao, 1974).

Economic Importance and Threshold Levels

The information available on the actual loss caused by *H. cajani* on pigeonpea is limited. Saxena and Reddy (1987) estimated 27.6 and 30.1% reduction in plant growth and grain yield, respectively. *Heterodera cajani* at the levels of 500 and 1000 juveniles per 500cc soil reduced the plant growth are visible within 40 to 45 days after inoculation. At sowing time, population density of more than two eggs and juveniles per cm^3 of soil may cause 30% reduction in plant biomass and grain yield. Zaki and Bhatti (1986) reported significant reduction in growth parameters in pigeonpea at 100 juveniles and above per kg soil. Pigeonpea grown in the root-knot nematode infested field can suffer significant damage. The avoidable yield loss in pigeonpea cv. Pusa Ageti due *Meloidogyne* spp. was assessed up to 14.2% in Gujarat particularly in the fields infested with a mixed population of *M. javanica* and *M. incognita* (Patel and Patel 1990). Root knot nematodes reduces the length and weight of plants, number of pods, bulk density of woody stem, chlorophyll content of leaves, root nodulation and water absorption capacity of roots (Anver and Alam, 1997). Pathak *et al.* (1985) observed significant reduction in plant growth with 100 juveniles of *M. incognita* per plant. Similarly, Mishra and Gaur (1989) could get pathogenic effect of *M. incognita* at a level of 100 juveniles and above in pigeonpea.

Interaction

Fungus: The interaction of *Fusarium oxysporum* f.sp. *ciceri* with *M.incognita* on chickpea cv. Dahod Yellow revealed that the organism, either individually or in combination, significantly reduced plant height and fresh root and shoot weights. The reduction caused by *M. incognita* was greater compared to *F.oxysporum* f.sp. *ciceri.* Among combined inoculations, the simultaneous inoculation of both organisms had maximum suppressive effect on the growth of chickpea plants compared to the preceding or succeeding inoculation of *F.oxysporum* f.sp. *ciceri* and *M. incognita.* Root galling and *M. incognita* multiplication on chickpea, which were maximum when *M.incognita* was inoculated alone, were reduced in the presence of *F. oxysporum* f.sp. *ciceri.* Alone was able to produce wilt disease increased when *M. incognita* was present with the fungus. Maximum wilting of plant was observed when the *F.oxysporum* f.sp. *ciceri* and *M. incognita* were inoculated simultaneously (Patel *et al.*, 1997).

The disease intensity of black root rot caused by *Fusarium solani* in chickpea is increased when root-knot nematode is inoculated with it. This combination also shortened the incubation period for disease expression (Mani and Sethi, 1987). Significant reduction in fresh shoot weight and number of nodules per plants has been observed by different researchers and the presence of nematodes increase the severity of the disease. The disease intensity of wet root rot index was high when inoculation of the nematode precedes that of *F. solani* (Mani and Sethi, 1987).

Combined inoculation of *M. javanica* and *Rhizoctonia bataticola* in chickpea seedlings reduce plant growth. The top root becomes dark, show sign of rotting and is devoid of the lateral and finer roots. The disease intensity of collar root caused by *Sclerotium rolfsii* was highest when the plants were infested simultaneously with fungus and root–knot nematode.

Bacteria: Nematode infestation on chickpea causes a remarkable reduction in rhizobium nodulation, thus causing indirect damage to plants. Nodule size decreases with increasing nematode density in CV 207, P256, G130 and K850. *Meloidogyne incognita* inhibits nodule development and affects functioning of nodules as reflected by nitrogenous activity, which may be due to leg hemoglobin and bacterial content of nodules. The reduction in plant growth characters is directly proportional to the reduction in nodulation. Since bacterial nodules are correlated with the nitrogen fixing ability of plant, root nodulation may cause deficiency of nitrogen, resulting in poor plant growth.

A study was conducted to evaluate the *Rhizobium* strains that nodulated the chickpeas and improved plant growth even in the presence of the root-knot nematode M. *incognita*. Chickpea cv. RSG 2 seeds were treated with different rhizobial strains (IC 94, CM 1, IC 149, IC 126, G 567, IC 53, IC 2018, CBH 32, G 10-80, DWG 4, KG 61, B1, TAL 1748, G5-B1, G37, KG 46, H60 and GB 2). The presence of nematode decreased the average growth and yield of chickpea plants. Plants from *Rhizobium*-treated seeds sown in nematode-infested soil had greater yield and plant growth than the control (untreated seeds).

Screening Technique

Efficient pot and field screening techniques have been standardised for screening large number of accession. Five to six surface sterilised seeds of each test line are sown in earthen pots containing autoclaved sandy loam soil. After two weeks of germination, seedlings are thinned to one plant per pot. 500 to 1000 freshly hatched nematodes or second stage larvae are introduced in the pots by pouring larval suspension in the soil around the seedling after three weeks of germination. After forty days of inoculation, the plants are uprooted and the number of galls and the egg masses produced on the root surface are counted. The extent of root-knot damage is rated according to the following scale: 1= no gall, 2= 1-25 galls, 3=36-50, 4=51-75, 5=76 and above.

Seeds of each test line are planted in rows with replication in a field known to have a heavy infestation of the nematode. Each test line is flanked by a highly susceptible check like REST 10. Five plants per replication are uprooted 45 days after sowing and nematode galls /egg masses are counted. The varieties are classified on a 0-5 scale.

Management of Nematodes

Nematodes can be managed in a number of ways. Seed treatment with chemicals, application of chemicals in the field, soil amendments, biocontrol and various means of cropping system have provided a promising result in the management of nematodes. Use of botanicals and soil amendments have proved to be environmentally safe and ecologically sound.

Soil Solarisation: The effect of solarisation by covering nematode infested soil with clear transparent polythene sheets for 6 weeks during the hot summer months reported increase in soil temperature (80°C) as compared with unsolarised check. It also resulted in a significant reduction in population densities of M. *incognita* (58.1%), *Fusarium oxyporum* f.sp. *ciceri* (80.6%). The availability of soil nutrients was increased

by soil solarisation but the physical and chemical characteristics of soil remained unchanged (Rao and Krishnappa, 1995).

Cropping System: Cropping systems have a regulatory effect on the nematode populations and it could be an effective nematode management. Host crops for cyst, root-knot, reniform, and lesion nematodes grown prior to pulse crops result in high build up of the nematode populations. A rapid build up of root-knot and reniform nematodes occurs when pulses are cultivated after vegetables. Non-host crops, when included in the system, reduce the nematode populations. Cereals such as pearl millet, sorghum, and wheat are generally not good hosts of the root-knot nematodes. Keeping the fields fallow and weed-free cause marked reduction in nematode populations. Intercropping of sorghum with cyst nematode-tolerant pigeonpea could be effective in increasing the productivity of traditional production systems in the nematode infested regions.

Densities of plant parasitic nematodes in traditional low input cropping system were three times lower than in high input cropping system. Sorghum/pigeonpea (intercropped) or soybean/pigeonpea (intercropped) were identified as system very conducive for the build up of *H. cajani.* The densities of plant parasitic nematode did not increase significantly in plots that were either fallowed or sown with pearl millet in the rainy season. A summer fallow period between February to June reduced the soil densities of all plant parasitic nematodes by 42%. *R. reniformis* population was reduced by 80%. *H. cajani, Tylenchorhynchus* spp. and all total plant parasitic nematodes densities were significantly higher in plots treated with inorganic fertilisers than in plots treated with farmyard manure. *R. reniformis* densities were higher in irrigated than in rainfed fields (Singh *et. al.*, 1994).

A significant reduction in nematode population was observed when the chickpea was sown late. This indicated that the late-sown chickpea may escape the nematode infestation and provide good yield. More than 50% reduction was noticed in the plant parasitic nematode population when the field was kept fallow (Ali, 1995).

Chickpea cv. R 56 was grown in beds where egg plant, okra, mung bean and cluster bean were established along with fallow plots. Population growth pattern in *M. incognita* was greatly influenced by preceding crops. Chickpea favoured free multiplication of *M. incognita.* The fallowing in the preceding season did not check the population development of the test nematode on chickpea (Alam and Saxena, 1986). The effect of four *kharif* crops (groundnut, sesame, soybean and tomato) and four rabi crops (wheat, mustard, chickpea and tomato) in different combinations giving 16 different

rotations on the population of *M. incognita* was studied in microplots. The rotation followed two years. There was manifold increase in level of population in tomato monoculture, while a substantial increase in population was observed in sequences having tomato in combination with chickpea and soybean. The maximum build up of *M. incognita* was on tomato followed by chickpea. The rotations having tomato in monoculture or in combination with soybean, chickpea and groundnut resulted in significantly low yield (Sharma *et al.*, 1997).

Population of *Meloidogyne* spp. declined on cotton, wheat and barley in all cropping sequences resulting in 10-15% increase in yield in subsequent cropping of chickpea in Pakistan (Maqbool, 1987). The population of *M. javanica* remained high in cropping sequence of okra-potato-ridge gourd (*Luffa acutangula*) and chickpea (Kanwar and Bhatti, 1992).

Root-knot nematodes on chickpea have been effectively controlled by inclusion of cereals or grasses in cropping system. Sesame, mustard and winter cereals are poor hosts of *M. javanica* and *M. incognita*, and 2-3 year rotations may be useful for disease management (Sharma *et al.*, 1992). *M. javanica* population was suppressed drastically under mustard-chickpea inter cropping system as compared to adjacent plots of sole chickpea (Anonymous, 1990). Effect of intercropping on pigeonpea infested with *M. incognita* revealed that maximum yield was obtained in plots where pigeonpea was intercultured with groundnut followed by sesame. The least number of nematode galls per plant were recorded in the sesame intercropped plants (Upadhyay and Dwivedi, 1997).

Biological Agents: Zaki and Maqbool (1991) reported that *Paecilomyces lilacinus* controls *M. javanica* by reducing root-knot indices when used @ 2 g per pot one week before nematode inoculation. The number of spores of Pasteuria *penetrates* @ 30 per juveniles of M. *javanica* provided more than 80% control of nematode in chickpea (Sharma, 1992). *Paecilomyces lilacinus* and *Bacillus subtills* were used by Siddiqui and Mahmood (1996) for the biocontrol of *Meloidogyne incognita* race 3 and *Macrophomina phaseolina.* Individually, *P. lilacinus* treatment was better against *M. incognita,* while *B. subtills* against *M. phaseolina.* The combined inoculation of both improved dry shoot weight significantly.

A study was conducted to determine the effect of using *T. harzianum and* neem cake alone and in combination to manage *M. incognita* in chickpeas cv. Type 3. Twenty clay pots were washed and filled with sterilised soil containing the mixture of neem cake at 10q/ha. Ten days after sowing, plants were inoculated with *M. incognita* and *T.*

harzianum at 1000 J_2 and 5000 spores per pot, respectively. The organic amendment and + *T. harzianum*, followed by neem cake and *T. harzianum* alone (Hemlata *et al.*, 2002).

Chemical: Carbofuran 3G @ 2 kg a.i. ha^{-1} as seed and soil application was highly effective in managing *Meloidogyne incognita* population and increasing yield in chickpea (Devi 1993). Pigeonpea seeds when treated with carbofuran (2%) eliminated root galling due to *Meloidogyne incognita* (Mishra 1986). The nematicidal seed treatments also reduced the population of nematodes in the soil by 45.2 to 70.6% (Anonymous 1981, 1987). Nematicidal effect on mungbean has also been observed in lowering down the population of root-knot nematodes (Sultan *et al.* 1985). Seed treatment and soil application of chemicals have been proved useful in lowering down the nematode population and increasing the yield of pigeonpea, mung bean, chickpea, fieldpea and urd bean.

Botanicals: Seed soaking on aqueous extracts of oil seed cakes (neem, mustard and karanj) and leaf extracts of *Canabis sativa, Eclipta alba, Datura metel, Argemone mexicana* and *Azadirachta indica* reduce the penetration of *Meloidogyne incognita* juveniles in chickpea (Mojumder and Mishra, 1991). Mojumder and Mishra (1992) tested neem seed coat both as soil and seed treatment against *M. incognita* and found significant reduction in root-knot galling and significant improvement in plant growth. The reduction in root-knot galls was more when soil treatments were combined with seed treatments. It also provided better plant growth. Soil treatment with neem seed coat at 2% w/w of soil resulted in maximum reduction in number of root-knot galls followed by seed kernel and seed coat in soil infested with *M. incognita* where chickpea was grown. All the treatment significantly reduced the number of root-knot galls and were significantly superior to check. Neem seed kernel was found most effective followed by neem cake. This finding indicated that chickpea is a good host of *M. incognita*, the infestation of which can be managed by applying aqueous extracts of neem seed kernel or neem cake @ 100 ml of standard extract per kg soil (Mojumder and Mishra, 1993a). Mojumder and Mishra (1993b) reported that seed soaking of chickpea seed in aqueous extracts of neem cake, neem seed kernel and seed coat also reduced penetration and developing of *M. incognita*. At 90 days there was more than 50% reduction in number of galls in almost all the treatments.

The population of plant parasitic nematodes *viz.*, *Meloidogyne incognita, Rotylenchulus reniformis, Tylenchorhynchus brassicae* and *Helicotylenchus indicus* and the frequently of pathogenic fungi *viz.*, *Macrophomina phaseolina, Rhizoctonia solani,*

Phyllostica phaseolina and Fusarium oxysporum f.sp. *ciceri* were significantly reduced by oil seed cake of neem, castor, mustard and duan (*Eruca sativa*) (Tiyagi and Alam, 1990).

Seed treatment with neem based laboratory formulations of neem seed kernel, neem seed cake @ 20% w/w reduced root-knot and reniform (*Meloidogyne incognita* and *Rotylenchulus reniformis*) nematode multiplication in two important pulse crops, mung bean and chickpea in greenhouse trials. All these treatments reduced major phytonematode species in the field, *viz.*, *M incognita, R. reniformis, Tylenchorhynchus mashhoodi, Helicotylenchus indicus* and *Hoplolaimus indicus* in both the crops in field trials in 4 sq. m. microplots. In either case, neem seed kernel was the most effective followed by neem seed cake and neem seed coat (seed shell). There was 78, 67 and 52 % reduction in total plant parasitic nematode population in the mung bean crop and the increase in the grain yield was 74, 58 and 28% neem seed kernel, neem seed cake and neem seed coat (seed shell) respectively. In the case of chickpea crop, the percentage reduction in the total plant parasitic nematode was 87, 76 and 25 and the increase in the grain yield was 122, 78 and 48, respectively in neem seed kernel, neem seed cake and neem seed coat (Mojumder and Raman, 1999).

Growing neem seedling along with chickpea cultivars Pusa 209 and Pusa 267 in $4m^2$ microplots (one seedling/plot) significantly reduced the plant parasitic nematode population such as *M. incognita, R. reniformis, T. mashhoodi, H. indicus* and *H. indicus* (*Basirolaimus indicus*). There was also a considerable increase in grain yield in both cultivars. However, there was not much difference between the cultivars in terms of treatments (Mojumder and Mojumder, 2002).

Wilt Complexes: Management of the root–knot nematode (*Meloidogyne incognita* and *M. javanica*) wilt (*Fusarium oxysporum* f.sp. *ciceri*) was studied in two chickpea varieties (Avrodhi, wilt resistant, and Dahod Yellow, wilt susceptible). Seed treatment of Carbendazim granules at 0.5% and carbosulfan at 0.75% along with soil application of Carbendazim granules at 0.5kg/ha in single dose + carbofuran granules at 2.0kg/ha in two equal splits (at sowing and 30 days after sowing) was studied. Grain yield production was significantly more in Dahod Yellow, but its fodder yield was significantly less than that of Avrodhi. The chemical treatment effectively managed the root-knot nematode-wilt complex (Patel *et al.*, 1987).

Root Symbiont: Plant parasitic nematodes are reported to interact with species of *Glomus*, *Gigaspora* and Sclerotium. These fungi reduce nematode population (Diedericks, 1987; Sharma *et al.*, 1992). Population of some nematode *viz.*,

Tylenchorhynchus sp., *Tylenchus* sp., *Helicotylenchus* sp. and *Hirschmanniella* sp. was observed in sufficient number in wilted plants (Sobin *et al.*, 1979).

A 90-day glasshouse experiment was conducted to assess the influence of a VAM fungus *Glomus fasciculatum,* a root nodule bacterium *Rhizobium* sp. and inorganic fertilizers [urea, diammonium phosphate (DAP), and muriate of potash] alone and in combination on the root-knot disease of chickpea (cv. Avrodhi) caused by *M. incognita.* Individual application of G. *fasciculatum* caused a similar increase in plant height and shoot dry weight of nematode -infected plants caused by *Rhyzobium* sp. DAP treatment gave greater plant height and shoot dry weight than urea or muriate of potash. *Glomus fasciculatum*, along with *Rhizobium* sp. DAP treatment was the best combination in improving plant height and shoot dry weight of nematode-infected plants. *Glomus fasciculatum* alone caused a higher reduction in root galling and nematode multiplication than *Rhizobium* sp., DAP, urea, and muriate of potash, respectively. Greatest reduction in root galling and nematode multiplication was observed when both the root symbionts by *G. fasciculatum* (Shafi *et al.*, 2002).

The effects of *Rhizobacteria, i.e., Pseudomonas fluorescens, Azotobacter chroococcum* and *Azospirillum brasilense*, alone and in combination with root symbionts, *Rhizobium* sp. and *Glomus mossae*, on the growth of chickpea and reproduction of *M. javanica* were studied. When added alone *G. mosseae* was better at improving plant growth to that caused by *Rhizobium* sp., while use of *A. chroococcum* was better than *A. brasilense* in improving growth of nematode infected plants. Combined use of *P. fluorescens with G. mosseae* was better at improving plant growth and reducing galling and nematode multiplication than any other combined treatment.

Crop Improvement for Nematode Resistance

The modern techniques of biotechnological gene transfer, cloning and mutation may go a long way in producing desirable nematode resistant cultivars. However, care must be taken of the vast variability and adaptability of nematodes. The varieties found resistant at one location may or may not show resistance to another population of the same nematode species due to prevailing races. Surfacing or emergence of resistance breaking biotypes after a few seasons of selection process is not new to nematodes. Therefore, resistant varieties should form a component of a well-planned crop rotation or other nematode management strategy.

In fact, researchers while releasing a new variety better keep in mind that it should be resistant to both fungus and nematode because if the variety is only resistant to fungus, the nematodes can break the resistance by providing entry points and changing the host physiology. Resistant plant acts as a barrier for nematodes in a number of ways

such as it retards the rate of reproduction, delays the maturity of the parasite, production of more males and making the nematodes unable to complete its development.

Host Plant Resistance

Research in the field of nematology and plant breeding has enabled to introduce varieties of pulse crops which have proved resistance to nematodes. In fact researchers while releasing a new variety keep in mind that it should be resistant to both fungus and nematode because if the variety is only resistant to fungus, the nematodes can break the resistance by changing the host physiology. Therefore, it becomes necessary for the breeders to keep both the objectives in mind prior to the release of a new variety. Resistant plant acts as a barrier for nematodes in a number of ways such as it retards the rate of reproduction, delays the maturity of the parasite, production of more males and making the nematodes unable to complete its development (Table 3).

Table 3: Resistance against key plant parasitic nematodes infesting pulse crops

Crops Nematodes	Resistance	Moderate Resistance	Susceptible	Reference
Chickpea *M. incognita*	Phule G0010, Phule G 96006, Vihar (PG 95311 Kabuli), IPCK 256, BG 2019, H 99-265	C235, CSJ 103, CSJ 146	Phule G 94091, Vijay (ch.), H 01-29, H 01-100, H 01-20, H 01-36, HK 98-155, PUSA 1053, PUSA 256, CST 253, CSJ 369, RSJ 957, RSJ 888, RSJ 931, RSJ 202, CSJK12, CSJP 125	Anonymous 2004c
Pigeonpea *M. javanica*	PA 291	JKE 109, JKE 110, JKM, 186, P-2001-1, PA 232, PA290, PA296, PA300, TT302, P-2001-2, P-2004-1	GAUT 0202, JKM 198, P-2004-2, SKN206, KNP207	Anonymous 2004b
H. cajani	NIL	GAUTO 202, JKM-198, PA-291, P-2002-2	JKM-186, JKE-110 JKE-109, PA-300	Anonymous 2004b

Lentil *M. incognita*	L-4076	NPL-3-11, L45-97, L 4670, L 4671, L 4674, L 4595, L 4666, L 4677, KLB-977, KLS 225	RLG-16, RLG14, L4147, L 45-98, L4676, L4672, KLS224, KLS 2003-3, KLS 218, HUL60, KLS2330-1, LL 887, LL906, LL 875, LL905, KLS 226, KLS 2003-2, PL023, PL02, PL01	Anonymous 2004a
M. javanica	L-4076	L-45-97, L4670, L4677, PL023	RLG-16, RLG-14, NDL 3-10, NDL 3-11, L-4671, L-4147, L-4674, L4672, L4595, L-4666, KLB 97-7, KLS-218, KLS 2330-1, LL-887, LL 906, KLS-225, K75, KLS226, KLS2003-2	Anonymous 2004a
Fieldpea *M. incognita*	NIL	IPFD 64-15, RFP-3, 1PFD-1-10, DPR-74, DMR 53, Pant P_{41}, Pant P_{31}, Pant P_{40}, HFP 4, HFP918, 2FP305, LFP363, HUP31, UDP27, HUDP 27, HUDP28	RFP-20 IPF99-25, IPFD54-6, IPFD 2-6, IPF 04-9, RPF-4, DMRF 52, DMR 48, DDR64, DMR-49, DMR-73, DMR-7, Pant P_{25}, HFP 4AVT (D) HFP 0110, HFP 0129, HFP4, HFP990713, HFP8903, HFP 0128, HUP30, HUDP 28, HUP2, HUDP15, Amlika, NDP2	Anonymous 2004a
M. javanica	RFP-4, HFP4 AVT(D), HFP0118	IPFP1-10, DMR-48, HUDP27	IPF 049, RFP3, DMRF52, DDR74, DPR-69, Pant P31, HFP4 AVT LFP363, HUP30, HUP31, HUDP2, HUP26	Anonymous 2004a
Rajmash *M. incognita*	NIL	HUR 137, HUR 401, IPR 98-3-1	HUR 202, HUR 203, 11PR98-2, Gujarat Rajma	Anonymous 2004a
M. javanica	NIL	NIL	HUR 202, HUR 137, HUR 401, HUR 2031, PR 98-3-1	Anonymous 2004a

New Methodologies: Three commercially adopted chickpea cvs. C 235, RSG 2 and RS11 were subjected to physical and chemical mutagens singly or in various

combinations. RS11 did not produce a single resistant mutant, whereas C 235 was more responsive than RSG2 and RS 11. Those isolated mutants were stable in morphological traits as well as in nematode reaction and could be utilised as parents for incorporating resistance (Bhatanagar *et al.*, 1988). Borada dhaki local and L 550 were irradiated with gamma rays (10, 20 and 30 KR) and fast neutrons and subjected to ethyl methane sulfonate (EMS, 0.05, 0.1 and 0.2%) methylmethane sulfonate (0.001 and 0.01%) treatments, either singly or in combination. Plants were screened for resistance to *M. javanica*. L550 was more responsive to mutagens. The mutant MV/7-1 produced the highest (yield 918.2g) under infested field conditions, it was obtained from the 30 KR+0.1% EMS treatment (Bhatanagar *et al.*, 1988).

Peroxides play an important role in the resistance mechanism of plants. It is a key enzyme required for lognin synthesis as well as their trapezoids involved in phytoalaexin production. Peroxidase catalyzes several reaction including those involved in the metabolism of phenols and indoles. On the other hand, protein content of galled roots has been used as an index of root-knot nematode infestation in okra plants. IC4928 to IC4842 (25 genotypes) were screened on the basis of increase in peroxidase activity. IC4942, IC4942, IC4944 were reported tolerant against *M. incognita* (Siddiqui and Hussain, 1992). Chickpea cv.K850 was inoculated with 1000-2500 J_2, *M. javanica*; after 60days, biochemical analysis revealed that there was an increase of 10-18 % and 26-54 % in total protein and amino acid contents, respectively, which was found greater in the stem and at the higher levels of infection. Increase in protein contents of chickpea was dependent upon the level of infection by root-knot nematodes (Upadhyay and Banerjee, 1986).

Biochemical and Molecular Approaches: Molecular cloning of numerous resistance genes from many different plants that are targeted against several pests and pathogens would permit the use of previously unavailable resistance in a particular crop plants and should lower the frequency with which newly virulent pathogen races become predominant. Although evidence is lacking for appearance of nematode resistance by somaclonal variation, there is good evidence that regeneration of plants via callus phase can be used to introduce sources of resistance into useful germplasm. This approach is best illustrated by the work studied on the introgression of resistance to the cereal cyst nematode, *H. avenae* from rye into wheat (Dasgupta *et al.*, 1995).

New technological developments, there are great opportunities to develop potent biocontrol agents, biorational novel nematicides that may target the nematode plant interaction, and bioengineering for nematode resistance. One of the strategies will be to

develop novel resistance through genetic transformation of host plant to produce phenotypes that disrupt or modify the normal host-parasite compatible interaction of nematodes and thereby, prevent nematode reproduction and possibly nematode infection. The use of nematode resistant crops, either alone or with integrated control programs, promises reduced or even eliminated. This strategy epitomizes effective biological disease control, *i.e.*, resistance which is heritable and, therefore, inexpensive and permanently available once introduces.

An alternative approach is to introduce a chromosomal fragment, which includes a desired gene into protoplasm, and then to regenerate a plant. The isolation of the appropriate DNA fragment is achieved by the separation of fragments by electrophoresis. The desired DNA fragment is then identified by autoradiography after hybridisation of DNA makers on southern blot isolated and introduced into protoplasts by direct gene transfer. This approach is awaiting application in the field of Nematology.

There are several approaches to the design of nematodes resistant transgenic crop cultivars. Perhaps the foremost is to identify and locate host plant resistance (HPR) gene(s) responsible for imparting resistance to the plant parasitic nematodes by constructing genomic libraries of interested crop plants and then transfer them to the susceptible cultivars using biotechnological tools of gene transfer. A common form of defense by plants is the production of broadly toxic secondary metabolites or biocides that give protection against a wide range of attacking or competing organisms. Plant phenolics can fulfil such a role. These metabolites are phase organic compounds which are not directly involved in the primary metabolic processes of plants, such as photosynthesis, respiration or the biosynthesis of proteins. Secondary metabolities include a wide variety of compounds, some classified generally by chemical function *e.g.*, plant phenolics and others, with widely varied functionality, by terms that state to their biosynthesis, *e.g.*, isoprepanoids. These metabolites may act as against toxicants or biocides, or may have a specific toxin action directed at a particular target. Alternatively, they may act as chemical messengers or signals with purely behavioural or regulatory effects (semiochemicals)

Analysis of the target site is important for both initial development of a novel control and for its integration in management programmes. Like stage specificity and route of action, *e.g.* via ingestion of direct contact, and sites of accumulation and transport routes in host tissues, are all factors that determine the efficacy and use of control tactics or agents. Nematode eggs are the only life stage components that content

chitin, an unbranched polymer, which is a primary structural component of the eggshell, providing physical strength and protection for more delicate underlying lipid layer. It is known that bacterial chitinase *in vitro* hydrolyses the nematode chitinous layer in *Onchocerca* eggs. Chitinas and other hydrolyses show direct effects on the root-knot nematode egg hatch and development of stunt and other nematode (Dasgupta *et al.*, 1995). Further, molecular manipulation for enhancing the target site action of the novel resistance gene product can be done by coupling with root-specific promoters to boost enzyme production in roots. Coupling with factors that promote site-specific gene action within root cells that are preferred feeding sites (for the ingestion route of action) or that promote transport into intercellular solutions (For direct contact route of action) may be also desirable.

Transgenics with Nematode Toxin Genes: Second approach in the designing of nematode transgenic host cultivars would be to introduce a nematode toxin gene under a constitutive promoter. This strategy has been adopted to design transgenic plants carrying the Bt gene that are resistant to insect pests. If a suitable toxin gene could be identified, this very approach can be used to construct nematicidal transgenic plants. But very few protein toxins that act specifically on plant parasitic nematode have been identified (Dasgupta *et al.*, 1995). *In vitro* exposure to Bt toxin caused aberrations in lipid layer of nematode egg. An important route for nematode toxicity may be, contact with Bt endotoxin rather than by ingestion. More studies are needed to decipher the nature of these molecules which are potentially used in designing nematicidal transgenic plants .If the toxin is a protein it would be possible to incorporate it into plants to function in a manner similar to Bt transformed plants.

The need is to identify products with antagonistic activity against nematodes with the aim to transfer the genetic information to suitable soil bacteria, assuming that these transgenic bacteria may be more effective then natural enemies. A completely different approach is based on the knowledge that some fungi and bacteria affect nematode development. Analysis of these nematicidal principles may reveal that in some cases only a limited number of proteins are involved. This opens the possibility to transfer the genes encoding these proteins to other organism. Expression in either soil bacteria, living around the roots of crop plants, or in crop plants themselves might lead to protection.

Techniques of molecular biology can help to resolve some problems of identification of plant-parasitic nematodes. Sequence variability occurs in most regions of the genome. When these change eliminate or create new restriction sites in DNA, this

variation, called restriction fragment length polymorphism (RFLP), can be measured by the number and size of fragments generated by digesting the DNA of different population with the same restriction enzyme. Many workers have used RFLPs to separate species and genera of plant parasitic nematodes. Nucleotide substitutions within non-coding regions (*i.e.*, introns) accumulate to the phenotype. The higher frequency of sequence differences facilities distinguishing population or strains that have separated recently. The PCR has been used to amplify genetic marker sequences with random primers and to amplify DNA from a single nematode juvenile shows a great promise (Dasgupta *et al.*, 1995).

Future Thrusts

The available literature on nematode problems of pulses clearly indicates that pulses are severely damaged by both ecto- and endo-parasitic nematodes. Visualising the importance of pulse crops, there is a great demand of managing these hidden micro-organism for which efforts should be made to find out economic management approaches which are less dependent on synthetic chemicals, environmentally safe, socially acceptable, technologically feasible and economically viable.

Keeping the negative points of chemical pesticides *viz.*, phytotoxic, costly, residue problems, pollution problems, human health risk etc., and the losses caused by plant parasitic nematodes in pulses in view, the emphasis has to be given on following thrust areas in future to reduce the incidence of phytophagous nematodes:

- Identification of resistant sources against key nematodes and their utilisation in breeding programme.
- Sincere efforts should be made to explore the possibility of using effective biocontrol agents under field conditions.
- Other economically viable and effective management practices need to be explored as alternatives to chemical management to reduce environmental pollution.
- Research on the possibility of using solar energy for nematode management under field conditions should be tried.
- Nematicidal efficacy of green plant materials should be investigated for nematode management both in nursery and in field condition.
- Integrated nematode management packages specials for the management of root-knot nematodes need to be developed.

- Information regarding distribution of important nematode species and the losses they cause on a regional basis should be generated.
- Research on the development of crop management strategies and cropping patterns should be encouraged for their different agro-climate zones.

References

Alam, M.M. and Saxena, S.K. 1986. Effect of preceding crop on the population growth pattern of *Meloidogyne incognita* and *Tylenchorhynchus brassicae* on chickpea cv. R. 56. *International Chickpea Newsletter* **14**: 33-34.

Ali, S.S. 1997. Status of nematode problem and research in India. In *Diagnosis of key nematode pests of chickpea and pigeonpea and their management* (Ed. S.B. Sharma). ICRISAT, Patancheru, India. pp. 74-82.

Ali, S.S. 1995. Nematodes associated with mung bean in Gwalior district. *Indian Journal of Pulses Research* **8** (1): 100-101.

Ali, S.S. 1995. *Nematode problems in chickpea.* Kanpur: Indian Institute of Pulses Research. Kanpur, India. 184p.

Anonymous 1981. All India Coordinated Research Project on Nematode Pests of Crops and their Control. Indian Council of Agricultural Research. *Proceedings IIIrd Workshop held at Tamil Nadu Agricultural University, Coimbatore*, 10-13 February, 1981, p 65.

Anonymous 1987. All India Coordinated Project on Plant Parasitic Nematodes with Integrated Approach for their control. *Proceedings of the workshop.* College of Agriculture, Pune, Mahatma Phule Agricultural University, Rahuri (Maharashtra), 9-12 June, p 128.

Anonymous 2004a. Annual Report 2004. All India Coordinated Research Project on MULLaRP Crop. Indian Council of Agricultural Research. *Proceedings of the workshop* held at Agriculture Training center, Narendrapur, Kolkata. 9-11 September, 2005, p 238.

Anonymous 2004b. Annual Report 2004. All India Coordinated Research Project on Pigeonpea Crop. Indian Council of Agricultural Research. *Proceedings of the workshop* held at ANG Ranga Agricultural University, Hyderabad. 4-6 May, 2005, p 231.

Anonymous 2004c. Annual Report 2004. All India Coordinated Research Project on Chickpea Crop. Indian Council of Agricultural Research. Indian Institute of Pulses Research, Kanpur, pp. 235

Anver, S. and Alam, M.M. 1997. Effect of root-knot and reniform nematodes alone and in combination on the growth of pigeonpea. *Nematologia Mediterranea.* **25** (1): pp. 13-15.

Anver, S. and Alam, M.M. 1997. Effect of root-knot and reniform nematodes alone and in combination on the growth of pigeonpea. *Nematologia Mediterranea.* **25** (1): pp. 13-15.

Balasubramanian, M. 1971. Root-knot nematodes and bacterial nodulation in soybean. *Current Science,* **40**: 69-71.

Bhatnagar, C.P., Handa, D.K. and Mishra, A. 1988. Kabuli chickpea mutants resistant to root-knot nematode, *Meloidogyne javanica. International Chickpea Newsletter.* **19**: 16-17.

Dasgupta, D.R., Ganguly, Sirohi, Anil, Pankaj and Raman, Rajgopal. 1995. Plant Parasitic Nematode Management: Physiological and Molecular Approaches. (Eds.) Gopal Swarup, D.R. Dasgupta and J.S. Gill. In: *Nematode Pest Management An Appraisal of Eco-friendly Approaches.* pp. 12-27.

Devi, S. 1993. Evaluation of carbofuran 3G as a seed and soil treatment against *Meloidogyne incognita* on gram. In: National Symposium on Recent Approaches in Integrated Nematode Management of Agricultural Crops. 6-7 August, 1993. Chowdhry Charan Singh Haryana Agricultural University, Hissar. 33 pp.

Diedericks, C. 1987. Interaction between five endomycorrhizal fungi and root-knot nematode. *Meloidogyne javanica* on chickpea under tropical condition. *Tropical Agriculture,* **64**: 353-355.

Ganguly, S. and Khan, E. 1989. Concomitant occurrence of population of *Heterodera cajani* and *Hoplolaimus indicus* on pulse crops in India. *International Nematology Network Newsletter* **6** (2) : pp. 15-16.

Greco, N. and Sharma, S.B. 1990. Progress and problems in the management of nematodes diseases. *In Chickpea in nineties. Proceedings Second, International workshop on chickpea Improvement,* ICRISAT, Pantancheru, India. pp. 135-137.

Hemlata, P., Gopal Pandey, Pant, H. and Pandey, G. 2002. Use of Trichoderma *harzianum* and neem cake alone and in combination on *Meloidogyne incognita* galls in chickpea. *Annalas of Plant Protection Sciences,* **10**: 175.

Kanwar, R.S. and Bhatti, D.S. 1992. Influence of cropping sequence on population of *Meloidogyne javanica* and crop yield. *Chaudhary Charan Singh Haryana Agricultural University Journal of Research* **22**: 40-45.

Manandhar, H.K. and Amtya, P. 1990. Effect of *Meloidogyne* spp. infecting on chickpea biomass and yield in Nepal. *International Chickpea Newsletter*, **22**: 39-40.

Mani, A. and Sethi, C.L. 1987. Interaction of root-knot nematode, *Meloidogyne incognita* with *Fusarium oxysporum* f.sp. *ciceri* and *F. solani* on chickpea. *Indian Journal of Nematology* **17** (1): 1-6.

Maqbool, M. A. 1987. Present status of research on plant parasitic nematodes in cereals and food and forage legumes in Pakistan. In *Nematodes Parasitic to cereals and legumes in temperate semi arid regions* (Eds. M.C. Saxena, R.K. Sikora and J.P. Srivastava), pp. 173-180.

Mhase, N.L. Shelk, S.S. and Ghorpade, S.S. 1997. Status of nematode problems and research on pulses in Maharashtra. In *Diagnosis of key nematode pests of chickpea and pigeonpea and their management* (Eds. S. B. Sharma), ICRISAT, Patancheru, India. pp. 95-98.

Mishra, S.D. and Gaur, H.S. 1989. Reaction of some chickpea, Cicer *arietinum* L. germplasms to the root-knot nematode, *Meloidogyne incognita Int. Nematol. Network Newsl.* **6** (1): 21-23.

Mishra, S.D. 1986. Control of root-knot nematode, *Meloidogyne incognita* infesting pigeonpea by nematicidal seed treatment. In: *Proceedings of National Symposium on New Dimensions in Parasitology*, University of Allahabad, 18-19 January, 1986 (Eds. Kapoor, V.N. and Mishra, S.L., Malhotra, S.K.) Allahabad, Uttar Pradesh, 34-36.

Mojumder, V. and Mishra, S.D. 1991. Nematicidal efficacy of some plant products and management of ***Meloidogyne*** *incognita* in pulse crops by soaking seed in their aqueous extracts. *Current Nematology* **2**: 27-32.

Mojumder, V. and Mishra, S.D. 1992. Management of root-knot nematode, *Meloidogyne incognita* infecting chickpea with neem seed coat. *Annals of Agriculture Research* **23** (4): 388-390.

Mojumder, V. and Mishra, S.D. 1993a. Soil application of aqueous extracts of neem products for the management of *Meloidogyne incognita* in chickpea. *Current Nematology* **4**: 105-108.

Mojumder, V. and Mishra, S.D. 1993b. Management of ***Meloidogyne*** *incognita* infesting pulse crops through seed treatments with neem product. *World Neem Conference India* **2**: 699-703.

Mojumder, V. and Mojumder, V. 2002. Effect of neem seedlings on major phytoparasitic nematodes associated with chickpea and on crop yield. *Pesticide Research Journal* **14**: 150-152.

Mojumder, V. and Raman, R. 1999. Comparative efficacy of neem based nematicidal products for management of nematode pasts of pulse crops. *In: Azadirachta indica* A. - Juss. P.P. Singh (Ed.), I.A.R.I., New Delhi, India, 223-234 pp.

Nath, R.P.; Banerji, A.K.; Haider, M.G. and Sinha, B.K. 1979. Studies on nematodes of pulse crops in India. Pathogenicity of *Meloidogyne incognita* on gram. *Indian Journal of Phytopathology.* **32** (1): 28-31.

Patel, B.A. 1997. Status of nematode problems and research on pulses in Gujrat. In *Diagnosis of key nematode pests of chickpea and pigeonpea and their management* (Eds. S.B. Sharma), ICRISAT, Patancheru, India. pp. 92-94.

Patel, R.G. and Patel, D.J. 1990. Pathogenicity and biochemical changes induced by reniform nematode, *Rotylenchulus reniformis* Linford and Oliveira, 1940 in pigeonpea. *Current Nematology* **1** (1): 11-14.

Pathak, A.K. and Godika, S. 2002. Plant growth and infestation by root-knot nematode *Meloidogyne incognita* in Rhizobium treated chickpea. *International Chickpea and pigeonpea Newsletter,* **9**: 24-25.

Rao, V. K. and Krishnappa, K. 1994. Variation in pathogenicity of *Meloidogyne incognita* on chickpea at different inoculum densities. *Indian Journal of Nematology,* **24** (1): 88-92.

Saxena, R. and Reddy, D.D.R. 1987. Crop losses in pigeonpea and mungbean by pigeonpea cyst nematode, *Heterodera cajani. Indian Journal of Nematology* **17** (1): 91-94.

Shafi, A., Mahmood, I. and Sissiqi, Z. A. 2002. Integrated management of root-knot nematode *Meloidogyne incognita* on Chickpea. *Thai Journal of Agricultural Science,* **35**: 273-280.

Sharma, S.B. and McDonald, D. 1990. Global status of nematode problems of groundnut, pigeonpea, chickpea, sorghum and pearlmillet and suggestions for future work. *Crop Protection.* **9**: 453-458.

Sharma, S.B., Ali, S.S., Patel, H.V., Patel, B.A. and Patel, S.K. 1993. Distribution and importance of plant parasitic nematodes associated with pigeonpea in Gujarat State. *Afro-Asian Journal of Nematology* **3** (1): 55-59.

Sharma, S.B. 1985. Nematode diseases of chickpea and pigeonpea. *Pulse Nematology Progress Report* 43. Patancheru, Andhra Pradesh, India. Legumes Programme ICRISAT, pp. 130.

Sharma, S.B., Ali, S.S., Upadhayay, K.D. and Ahmad, F. 1996. Potential nematode constraints of pigeonpea in Uttar Pradesh in northern India. *Afro-Asia Journal of Nematology* **6** (2): 151-155.

Sharma, S.B., Reddy, B.M.R. and Krishnappa, K. 1992. Incidence and importance of plant parasitic nematodes on pigeonpea and groundnut in Karnataka state in southern India. *Afro-Asia Journal of Nematology* **2**: (1-2) 21-26.

Siddiqui, Z.A. and Husain, S.I. 1992. Response of 20 chickpea cultivars to *Meloidogyne incognita* race 3. *Nematologie Meditereanea* **20** (1): 33-36.

Siddiqui, Z.A. and Mahmood, I. 1996. Effect of *Heterodera cajani, Meloidogyne incognita* and *Fusarium udum* on the wilt disease complex of pigeonpea. *Indian Journal of Nematology* **26** (1): 102-104.

Singh, J. and Rao, A.S.H. 1974. Quantitative estimation of viable *Heterodera* cyst in Arhar (*Cajanus cajan*) field at Varanasi. *Indian Journal of Zoology* **14** (1) : pp. 14-21.

Singh, M., Sharma, S.B. and Anders, M.M. 1994. Plant - parasitic nematode densities in cereal and legume based cropping systems on vertisols, *Afro-Asian Journal of Nematology* **4** (1): 44-50.

Singh, R.V. and Gill, J.S. 1989. Occurrence and distribution of plant parasitic nematodes in India as revealed by surveys conducted from 1977-1988. *Report of All India Co-ordinated Research Project* (Nematodes) pp. 43.

Sobin, N., Nema, K.G. and Dave, G.S. 1979. The possible interrelationship between plant parasitic nematodes (*Tylenchorhynchus*) and root-rot fungus from gram (*Cicer arietinum* L.) In *Physiology of Parasitism* (Eds. G.P. Agarwal and K.S. Bilgrami). Current trends in life sciences. Today and Tomarrow Publishers, New Delhi, India. pp. 451-456.

Sultan, M.S., Singh, I. and Sharma, S.K. 1985. Efficacy of some nematicides for the control of root-knot nematode infesting mung. *Nematologia Mediterranea* **13**: 2, 257-259.

Tiyagi, S.A., and Alam, M.M. 1990. effect of root-knot, reniform and stunt nematodes on plant growth, water absorption capability and chlorophyll content of chickpea. *International Chickpea Newsletter.* **22**: 40-42.

Upadhyay, K.D. and Banerjee, H. 1986. Some chemical changes in chickpea plant infected with root-knot nematode, *Meloidogyne javanica. Indian Journal Nematology.* **16** (2): 286-288.

Upadhyay, K.D. and Dwivedi, K. 1987. Root-knot nematode, *Meloidogyne javanica* breaks wilt resistance in chickpea variety Avrodhi. *Current Science,* **56** (17): 915-916.

Varaprasad, K.S., Sharma, S.B. and Loknathan, T.R. 1997. Nematode constraints to pigeonpea and chickpea in Vidarbha region of Maharashtra in India. *International Journal of Nematology.* 7 (2): 152-157.

Zadi, S.B.I., Ahmad, S., Khan, S. and Siddiqi, M.B. 1988. Comparative studies on the extent of damage caused by root-knot and reniform nematodes on chickpea. *International Nematology Network Newsletter,* **5** (4): 12-13.

Zaki, F.A. and Bhatti, D.S. 1986. Pathogenicity of pigeonpea cyst nematode, *Heterodera cajani*, Koshy 1967 on some pulse crops. *Indian Journal of Nematology.* **16** (1): 30-35.

Zaki, M.J. and Maqbool, M.A. 1991. *Paecilomyces lilacinus* controls *Meloidogyne javanica* on chickpea. *International Chickpea Newsletter,* **25**: 22-23.

❑❑❑

2

Nematode Problems in Vegetable Crops

Anil Kumar and R.K. Jain

Introduction

Vegetables are the most important priceless blessings that nature has bestowed upon mankind. They are not only rich in vitamins 'A' and 'C' and minerals like calcium and iron but also have low calorific values and low in fats. The destructive plant parasitic nematodes are one of the major limiting factor in vegetable production through India. Because vegetables are grown throughout the year so they harbor and encourage the build up of nematode population.

For centuries, man has been plagued by these microscopic organisms feeding on the roots of crop plants essentials for their survival and well being. Roots damaged by the nematodes are not efficient in the utilisation of available moisture and nutrients from the soil resulting in reduced functional metabolism. Visible symptoms of nematode attack often include reduced growth of individual plants. Furthermore, roots weakened and damaged by nematodes are easy prey to many types of fungi and bacteria, which invade the roots and accelerate root decay. These deleterious effect on plant growth result in reduced yields and poor quality of crops. Nematode management is therefore, important for high yields and quality that are required by the high cost of modern crop production.

Root-knot Nematodes: *Meloidogyne* spp.

The root-knot nematodes are by far the most important pests of vegetable crops. The four most common species *viz., M. incognita. M. javanica, M. hapla and M. arenaria* are by far most important and leads to formation of conspicuous root galls. *M. incognita* and *M. javanica* are most widespread in distribution and have a wide host range among vegetables, whereas *M. hapla* is encountered and poses problem under temperate conditions and attacks potato and other vegetable crops while *M. arenaria* infects chillies. Four races in *M. incognita,* two each in *M. javanica* and *M. arenaria* have been reported from India.

The most important species of root-knot nematodes *(Meloidogyne incognita* and *M. javanica)* attacking vegetable crops are multivoltine. Eggs are laid in a gelatinous matrix surrounding the posterior portion of each female. These eggs undergo embryogenesis, first moult takes place inside the egg and second-stage juveniles emerge out. These pre-parasitic second-stage juveniles move freely in the soil and are attracted towards roots from as far as 75 cm.

Physiological races/biotypes are known to be prevalent in a few species of root-knot nematodes. The international *Meloidogyne* project has identified four races in *Meloidogyne incognita* and two in *M. arenaria.* In India, researchers reported four races of *M. incognita.* In Haryana and Karnataka, existence of four races of *M. incognita, i.e.,* race 1, 2, 3 and 4 has been reported. The prevalence of race 4 that is very rare (2% of 472 world populations) has been reported for the first time from India.

The inoculum level varying from 0.5 to 1.0 per g soil in different vegetable crops, *viz.,* tomato, brinjal, okra, curcurbits, radish, turnip, pea and Chinese cabbage has been found to be pathogenic. Infected plants are stunted with dried peripheral branches bearing smaller chlorotic leaves almost turning to white in later stages.

Basically root-knot nematodes are parasites of roots or underground stem. The disease caused by root-knot nematodes is not of epidemic nature but rather of slow decline in yields spreading very gradually and steadily year after year. Some areas within a field may be severely affected, whereas plants in other parts may not show any sign of disease.

The aboveground parts of the diseased plants exhibit symptoms typical of mineral deficiency or drought injury even in the presence of adequate fertilizer and moisture. The other symptoms may include-dieback, yellowing, wilting and premature shedding of the foliage with severe stunting, depending upon the initial nematode population in the field. Chlorosis of the foliage lowers the quality of the crop resulting in severe losses.

The belowground symptoms include galls or knots on the roots. These galls vary in size from pinhead to a large size, which in case of heavy infection may coalesce to form large secondary galls. The size of galls also depends upon the host plant and nematode species. The galls produced in curcurbits are much larger than the ones produced on chillies or cotton by the same nematode species. *M. hapla* usually produces small galls as compared to *M. incognita* or *M. javanica* on potato. Besides galling, some other typical symptoms in the form of forking of tap roots as in carrots or beet and pimple-line tubercles on tubers (potato) are also manifested.

The root-knot nematodes, *Meloidogyne incognita* were of the limiting factors in commercial production of vegetables and responsible for 15-60% yield loss (Krishnappa *et al.*, 1992). Various researchers reported a loss of 70 per cent in chillies, brinjal, tomato and okra. In Mahendragarh district of Haryana, in a field naturally infested with *M. incognita* at 2800-3460 larvae per kg soil, losses in yields of okra, tomato and brinjal were 90.9, 46.2 and 27.3 per cent, respectively. Yield of tomato was reduced by 39.8 per cent in a field at population level of 20 larvae per g of soil. In peas, the avoidable loss in yield was found to be 19-20 per cent. In Tamil Nadu, losses in yields of Capsicum and tomato were 19.7 and 61.0 per cent, respectively, due to *M. incognita.* In Haryana, in a field having initial *M. javanica* population of 296±51 per 250 g soil, the avoidable losses in okra yield ranged from 20.2 to 41.2 per cent by using carbofuran and aldicarb @ 2.0 and 4.0 kg a.i. per ha. Per cent avoidable losses in yield of okra, brinjal, French bean and cowpea due to *M. icnognita* under field conditions at Bangalore were 28.08, 33.68, 43.48 and 28.60, respectively. Yield losses in tomato, brinjal and bittergourd due to *M. incognita* race 3 under field conditions in Maharashtra were 46.92, 32.73 and 36.72 per cent, respectively.

The Reniform Nematode: *Rotylenchulus reniformis*

The reniform nematode infests tomato, brinjal, okra, cowpea, dolichos, French beans, parwal and other vegetables. Two races of this nematode have been reported from India (Dasgupta & Seshadri, 1971). The emergence of cowpea seedlings was delayed by 7 to 9 days and seedling stand was reduced to the tune of 6 to 11 per cent due to *R. reniformis* at one nematode per g of soil. *R. reniformis* was observed to cause stunted growth of mint plants, withering of branches with chlorotic leaves at Hessaraghatta near Bangalore.

Comprehensive work done by various researchers has established the existence of two biotypes (A and B) in *R. reniformis.* Biotype A completes its life cycle on all the three differential hosts (cowpea, castor and cotton) while biotype B would not complete its life cycle on castor or cotton. The two races were found to interbreed with each other and the hybrids were fertile and more polyphagous than the parents.

Root Lesion Nematodes (*Pratylenchus* spp.)

Nematodes belonging to this genus are designated as lesion nematodes because of the severe necrotic lesions that are produced in the feeding sites in root cortex. De Man described the first species of *Pratylenchus* in 1880. At present, there are more than 68 species in this genus in the world (Siddiqi, 1986). However, in India, a total of 36 species

have been recorded so far (Walia, 1986). Amongst vegetables, tomato is an important host for this nematode. At least five spp. *viz.*, *P. brachyurus*, *P. coffeae*, *P. penetrans*, *P. scribneri* and *P. vulnus* have been reported to infect tomato (Jensen, 1972).

Of the different species of *Pratylenchus* present in India, Das described *Pratylenchus indicus* in 1960 from Hyderabad on tomato and brinjal. It is widespread in the states of Kerala, Gujarat, Orissa and Assam. *Pratylenchus* species have cosmopolitan distribution with a wide host range including vegetable crops such as peas, pepper, spinach, radish, onion, brinjal and beans etc. *P. penetrans* is economically most important in North eastern states of USA (Mai *et al,* 1977). However, it is also present in Canada (Potter & Olthof, 1974) and Europe (Loof, 1978).

The life cycle is simple the reproduction is sexual. The eggs are deposited singly mostly in roots. The first moult takes place inside egg and the second stage larva hatches out, which moults three times to become adult. Both larval stages and adult are capable of entering the roots. The nematodes overwinter in the single adults and fourth-stage larvae and eggs in the roots. The time required for completing one life cycle ranges from 90 days depending upon the prevailing soil temperature, host plant and nematode species.

Root lesion infected plants show gradual decline or lack of plant vigour with stunting as chlorosis leading to rapid wilting. On the roots, there is formation of lesions and necrosis, which provided site for other micro-organisms to infect, grow and reproduce, thereby leading to other disease complete. Shafiee & Jenkins (1962) noticed that growth of all the plants was retarded due to nematode infection. The phosphorus deficient plants did not exhibit such response. However, marked reduction in plant growth as observed in N-deficient plants.

Nematodes belonging to this genus are endoparasitic root feeders which migrate inter and intracellularly and feed in the cortical region leading to cell death and breakdown. Formation of lesion on the roots due to nematode feeding can be seen, which enlarge, coalesce and turn brown and ultimately affected area gets sloughed off. This results in the reduction of proper root development. In pepper, destruction of parenchymatous cells of cortex accompanied by dark and thick cell walls has been observed (Mai *et al.*, 1977).

Root cells of many plants contain glycosides (*e.g.* amygdalin), which are not toxic in glycosidic ion. However, upon hydrolysis they release certain phytotoxic compounds. Mountain and Patrick (1959) reported the *P. penetrans* hydrolyses amygdalin in peach roots due to the secretion of β-glucosidase, releasing benzaldehyde

and hydrogen cyanide, both of which are highly phytotoxic substances. Further, oxidation of these substance in the roots is believed to be responsible for browning of lesions and root necrosis.

McKeen & Mountain (1960) observed synergism between *Verticillium albo-atrum* and *P. penetrants* brinjal. They found that when present alone, even as high as 4,000 nematodes per plant were unable to the damage. But, in presence of wilt fungus, severe crop damage could be seen. On tomato and pepper, the nematode population was higher in presence of *Verticillium* than in its absence (Olthof and Reys, 1969). Conroy *et al.* (1972) found no increase in the susceptibility of tomato to V *albo-altra* in the absence of *P. penetrant*. Mountain and McKeen (1965) reported that reproduction of *P. penetrant* increased in presence of *V. dahliae* on tomato and egg plant but not on pepper.

Spiral Nematode, *Helicotylenchus dihystera*

H. dihystera causes perceptible reduction in root growth of chillies. Okra. Tomato, brinjal and onion were also found to be good hosts for this nematode.

Potato Cyst Nematodes, *Globodera* spp.

The potato cyst nematode *(G. rostochiensis* and *G. pallida)* is the most important pests of potato. This nematode has been reported from Nilgiris and Kodai Hills of Tamil Nadu and Munar Hills of Kerala (Ramana and Mohandas, 1988). Out of 9,000 ha under potato, 3,000 ha are infected by this nematode in Nilgiris. In Kodai Hills, about 200 ha are infected (Thangaraju, 1983). Tomato and brinjal are also attacked by this nematode. Total failure of the crop has been reported under severe infestation conditions.

Stunt Nematodes *(Tylenchorhynchus* spp.)

Nematodes belonging to this genus are widely distributed. These are rot parasites and are found in almost all the areas. The most common species feeding on vegetables in India is *Tylenchorhynchus brassicae*. The nematode is associated with poor germination and growth of cabbage and cauliflower. Although widely distributed both in temperate and tropical zones, yet only a few species are known to be pathogenic to various vegetable crops. In southeastern USA, *T. claytoni* has been responsible for stunting of pea and *T. marioni* in sweet potato. *T. brassicae* damages cabbage and cauliflower. *T. dubius* parasitizes cauliflower, pea, radish and turnip in the Netherlands (Brezeski, 1971). Besides cauliflower and cabbage, tomato, radish, sugarbeet and lettuce are also good hosts.

Stunt nematodes primarily feed ectoparasitically on epidermal cells of roots in

the region of root elongation but are sometimes embedded partly or totally in the root tissues. In India, *T. brassicae* has been observed to penetrate throughout the cortical region. Nematodes remain confined to outer cortical layers with their bodies parallel to the root axis. Populations at and above 1000 per kg soil cause significant damage to cabbage and cauliflower. The nematode feeding results in stubby root condition leading to stunting and reduced plant growth. The optimum temperature for growth and reproduction is around 30°C with 25-30 per cent moisture (Khan, 1969). In the absence of host, the nematodes survive for 90 days and 30 days at 35°C and 45°C, respectively. At low temperatures, the nematode may survive even upto 240 days. *Rhizoctonia solani* and *T. brassicae* are often associated with roots of cabbage and cauliflower. *R. solani* alone suppressed the emergence of cauliflower seedlings by 81% when the two organisms occurred together 97% of the seeds failed to germinate (Khan and Saxena, 1969).

The Stubby Root Nematode, *Trichodorus allius*

T allius infects onion.

The Stem and Bulb Nematode, *Ditylenchus destructor*

The stem and bulb nematode, *D. destructor* causes dry root of potato tubers in Shillong.

MANAGEMENT METHODS

Regulatory Methods

Plant Quarantine

From the imported gerinplasm material, economically important nematodes like *Heterodera goettingiana, Meloidogyne incognita, Ditylenchus dipsaci, Radopholus similes* (Sethi *et al.,* 1972) and *Globodera rostochiensis* (Renjhen, 1973) have been intercepted.

In India, there is a Quarantine Act against the cyst nematode of potato *(Globedera rostochiensis)* in Nilgiris. Infected seed potatoes from Nilgiris are not allowed to be transported to other parts of India for seed purpose.

Seed Certification

Seed pieces free of the cyst nematode can be produced commercially by seed certification.

Physical Methods

Heat Treatment of Soil

The most important nematode pests controlled by greenhouse steaming are cyst nematode of potato attacking tomatoes and root-knot nematodes on tomatoes, cucumbers and lettuces.

Incubation of potato tubers at 45°C for 48 hours has been shown to kill about 98.9 per cent *M. incognita* without affecting tuber viability (Nirula and Bassi, 1965).

Cultural Methods

Crop Rotation

Crops, which have been shown to reduce root-knot populations in the soil include varieties of cereals (sorghum, millet, maize, wheat, rice), cruciferous crops (cabbage, cauliflower, kohl rabi, mustard), onion, garlic, groundnut, cotton, Roselle *(Hibiscus sabdariffa)* and pigeon pea.

Continuous cropping with potatoes increases the cyst population of *Globodera rostochiensis.* More than three-year rotations with wheat, strawberry, cabbage, cauliflower, peas, maize and beans reduces the nematode population to a safe level. Likewise, decrease in root-knot nematode population on tomato, brinjal, okra, chillies and spongegourd occurs following marigold and spinach (Khan *et al.,* 1975).

There was sudden decline in population of *Tyhlenchorhynchus brassicae* when cabbage and cauliflower were rotated with wheat (Siddiqui *et al.,* 1973). The mustard (rabi), radish (summer), sesamum (kharif) sequence considerably reduced the population of *Tylenchorhynchus* spp. (Haque and Gaur, 1985).

A number of crops and other plants are reported resistant to the reniform nematode, *Rotylenchulus reniformis* which include chillies, *Lecaena glauca, Capsicum ftutescens,* carrot, coriander, *Spinacea oleracea, Beta vulgaris* and *Raphanus sativus* (Khan and Khan, 1973). Two successive crops of maize or sorghum preceding susceptible crops are effective in controlling *R. reniformis.* Rotations with sugarcane and pangola grass are recommended for control of the reniform nematode.

Selection of Healthy Propagating Material

The potato cyst nematode *(Globodera rostochiensis)* can be eliminated by selecting nematode-free planting material.

Influence of Manuring

Increased levels of potash have significantly reduced the number of galls by *M javanica* in tomato (Gupta and Mukhopadhyaya, 1971). Application of potash in combination with phosphorus or nitrogen or potash alone checks the reniform nematode multiplication on okra to a great extent (Sivakumar and Meerazainuddin, 1974).

Trap Cropping

Cowpea causes the root-knot nematode eggs to hatch, the larvae enter the roots and develop to immobile stage. Then the crop is destroyed before the nematodes mature.

Crotolaria is highly susceptible to invasion by the root-knot nematode but is resistant to the development of larvae into adults.

Enemy Plants

Mustard: Potatoes grown with white mustard in a pot of infested soil were less heavily attacked by nematodes than potatoes growing alone. Potato root diffusate was ineffective in the presence of Teachings from the roots of mustard seedlings. Mustard oils increased the yield of potatoes by reducing the severity of nematode attack. The active principle involved in mustard is allyl isothiocyanate, which is toxic to the nematodes.

Marigold: The root-knot development on tomato and okra was low when interplanted with *Tagetes erects.* The population of *Tylenchorhynchus, Helicotylenchus, Hoplolaimus, Rotylenchulus* and *Pratylenchus* was also markedly reduced (Khan *et al.,* 1971a; Alam *et al.,* 1977). Alpha-Terthienyl is the active principle in *Tagetes* spp., which is toxic to these nematodes.

Asparagus: *Asparagus officinalis* would not support populations of *Trichodorus chirisitiei* for more than 40 to 50 days. Tomato, normally a good host of this nematode, supported only a low population when asparagus was growing in the same pots. A glycoside (asparagiusic acid) is the active principle involved which is toxic to *T. christiei* and several other nematode species.

Sesame: Atwal and Manger (1969) showed that root exudates from sesame *(Sesamum orientate)* have nematicidal properties against *M incognita. When* okra was grown in *M incognita* infested soil it was only slightly attacked and there were fewer nematodes compared with when okra was grown in the absence of sesame.

Time of Planting

Planting of potato during third or fourth week of March in Shimla Hills would

reduce the damage to *M incognita* (Prasad *et al.*, 1983). The yields were maximum, which was concomitant with the lowest tuber infestation and lowest larval population in the soil at harvest.

Chemical Methods

Nursery Bed Treatment

Nursery bed treatment with aldicarb and carbofuran both at 2 g a.i. per m^2 were effective in increasing seedling growth and reducing root-knot nematode population on tomato, brinjal and chillies (Jain and Bhatti, 1983; Ramakrishnan and Balasubramanian, 1981). In the main field, the above treatments were also effective and increased the fruit yields.

DBCP at 50 liters per ha and metham sodium at 250 liters per ha were effective in reducing the renifonn nematode population in tomato nursery, and in increasing the growth of seedlings (Sivakumar *et al.*, 1977).

Seed Treatment

Fenamiphos, aldicarb and carbofuran all at 1 per cent concentration were effective in controlling the root-knot nematode *(M. incognita)* infecting cowpea, French bean and peas and in increasing their pod yields (Parvatha Reddy, 1984). Seed treatment with aldirab and carbofuran both at 6 and 12 per cent was effective against the root-knot and reniform nematodes infecting okra (Shivakumar *et al.*, 1976). Aldicarb and carbofuran at 3 per cent were also effective against root-knot nematodes infecting chilli and bottle gourd (Kandasamy and Shivakumar, 1981). Jain and Bhatti (1981) reported effective control of *M. javanica* on okra by seed treatment with fenamiphos at 2, 4 and 6 per cent.

Seedling Bare-root Dip Treatment

Carbofuran and oxamyl at 1,000 ppm for 15 to 30 min. (Parvatha Reddy and Singh, 1979); fenamiphos at 250 to 750 ppm for 30 min. (Thakar and Patel, 1985); dimethoate at 500 ppm for 6 hr, phosphamidon and dichlofenthion both at 1000 ppm for 8 hr (Jain and Bhatti, 1978) and thionazin at 500 ppm for 15 min (Reddy and Seshadri, 1975) gave effective control of root-knot nematodes on tomato when used as bare-root dips. Alam *et al.* (1973) reported that oxamyl was effective for the control of root-knot nematodes infecting brinjal and okra.

Bare-root dip treatment of brinjal seedlings with aldicarb, carbofuran and turbofos at 500 to 1000 ppm was effective in reducing the reniform nematode population.

Soil Treatment in the Main Field

Aldicarb, carbofuran, ethoprophos and fenamiphos each at 1 to 2 kg a.i. per ha were found effective in reducing the root-knot nematode population and in increasing fruit yields of different vegetable crops (Ahuja, 1983; Singh *et al.*, 1978; Rao and Singh, 1978; Singh and Parvatha Reddy, 1981b, 1982b; Parvatha Reddy, 1985a; Handa & Mathur, 1981).

Aldicarb at 0.5 kg a. i. per ha and carbofuran at 1.5 kg ai per ha were effective in reducing *Tylenchorhynchus brassicae* and *T. dubius* population and in increasing yields of cabbage (Varma *et al.*, 1978).

Reddy and Seshadri (1972) reported that thionazin at 4 kg a.i. per ha proved effective against *R. reniformis* infecting tomato.

Host Resistance

Screening of Germplasm

Source of resistance have been identified in certain vegetable crops. Nematode-resistant varieties of a very few vegetable crops have been developed and identified which are given below in Table-l. Nematode-resistant cultivars of vegetable crops.

Crop	Nematode	Resistant cultivars	References
Tomato	*Meloidogyne* spp.	Nematox, Sl-120, NTR-1, SL-12, Patriot, VEN-8, VFN Bush, Piersol, Radiant, Nemared, Ronita, Anahu, Bresch, Helani, Campbell-25, Punuui, Arka Vardan, Pelican, Hawaii-7746, Hawaii-7747, Hisar Lalit	Patel *et al.*, 1979; Jain *et al.*, 1983; Kanwar and Bhatti, 1990
Brinjal	*M. incognita*	Giant of Banaras, Black Beauty, Gola	Alam *et al.*, 1974
Chilli	*M. javanica*	579, CAP-63, Pusa Jwala	Jain *et al.*, 1983
Potato	*M. incognita Glodobera rostochiensis*	Kufri Dewa, Kufri Swarna	Raj and Gill, 1983
Cowpea	*M. incognita*	Barsati Mutant, Iron, New Selectin, G-152, 92-1-B, IC 9642-B, TVU 2439-P	Sharma and Sethi, 1976a, Darekar and Patil, 1981

French bean	*M. incognita*	Banat, Blue Lake, Stringless, Bountiful Flat, Brown Beauty, Cambridge Countess, Gallaroy, Kenya-3, Pinto W5-114, Seafarer, Suttan's Masterpiece	Singh *et al.*, 1981
Muskmelon	*M. incognita* *M. Jaanica*	Scarsol, S-445	Khan *et al.*, 1971b, Jain *et al.*, 1983
Watermelon	*M. incognita*	Shehjanpuri	Khan *et al.*, 1971b
Ridgegourd	*M. incognita*	Panipati, Meerut Special	Khan *et al.*, 1971b
Ashgourd	*M. incognita*	Jaipuri, Agra	Khan *et al.*, 1971b
Pumpkin	*M. incognita*	Jaipuri, Dasna	Khan *et al.*, 1971b
China aster	*M. incognita*	Shashank-Resistant, Poornima-Mod, Resistant	Nagesh *et al.*, 1995

Among four species of *Solanum* tested for their reaction against *M. incognita, S. torvum* and *S. seaforthianum* gave resistant reaction, which was reflected in the reduction in number of galls, egg masses and fecundity of females (Shetty and Reddy, 1985b).

Biological Methods

Singh and Sitaramaiah (1966) applied finely divided oil cakes to rootknot infested soil and noted a reduction in disease incidence in okra and tomato. Amendment of soil with oil cakes of neem, groundnut, mustard and castor was effective in reducing the population of *Tylenchorhynchus brassicae* around the roots of cabbage and cauliflower (Siddiqi *et al.*, 1976). The above cakes were also effective in reducing parasitic nematode population *(Hoplolaimus, Tylenchorhynchus, Meloidogyne* and *Helicotylenchus species)* and in increasing yields of tomato, potato, carrot and tumipt. It has been reported that neem and karanj oil cakes at 2 tons per ha were most effective in reducing *Rotylenchulus reniformis* infecting French bean.

Best results in respect of root-knot reduction due to *M javanica* and increase in yield of okra and tomato were obtained by amending the soil with saw dust at 2.5 tons per ha 3 weeks before planting and then applying N through urea at 120 kg per ha (Singh and Sitaramaiah, 1971). Rice hull ash at 2.5 tons per ha increased the yield of tomato by 133 to 317 per cent and reduced root-knot incidence by 46 to 100 per cent (Sen and Dasgupta, 1981).

Paecilomyces lilacinus is an effective parasite of *Meloidogyne* eggs. Egg parasites are more dramatic in reducing the nematode population. Nematode eggs of the group Heteroderidae and those deposited in a gelatinous matrix are more vulnerable to attack by these organisms than are those of migratory parasites. Once in contact with the cysts or egg masses, the fungus grows rapidly and eventually parasitizes all the eggs that are in the early embryonic developmental stages.

P. lilacinus was found effective against *M incognita* on potato and tomato, *G. rostochiensis* on potato, *R. reniformis* on tomato and brinjal (Parvatha Reddy and Khan, 1988, 1989).

Application of different oil seed-cakes improved the growth of Japanese mint in field conditions coupled with increased oil yield and reduced root-knot nematode population. However, best results were achieved when the soil was treated with neem cake (Haseeb, 1992). Neem cake was also effective against *M incognita* infecting basil *(Ocimum basilicum)* and increased plant growth and oil content (Haseeb *et al.*, 1988a).

Isolation of Nematicidal Plant Products

Methanol extracts of *Catharanthus roseus*, onion, *Gloriosa superba* scented geranium exhibited nematicidal activity against root-knot nematodes. The active nematicidal compounds identified were citroneliol, geraniol and linalool from scented geranium essential oil; colchicine from *Gloriosa superba* seeds; serpentine from *Catharanthus roseus* and amino acids (Methionine) from onion seeds. The feasibility of utilisation of serpentine at 5000 ppm for the management of *M. incognita* in tomato nursery was ascertained (Leela *et al.*, 1992)

Integrated Methods

Integration of a bioagent- *Paecilomyces lilacinus* and carboflaran at 2 kg a.i. per ha was found to be effective in the management of reniform nematode Rotylenchulus reniformis on tomato (Parvatha Reddy and Khan, 1988). Inoculation of endomycorrhizae *Glomus mosseae* or *G. fasciculatum* in the nursery beds amended with neem cake/castor cake/neem leaf/calotropis leaf helped in reducing the infestation of root-knot and reniform nematodes to the maximum extent. Amendment of botanicals in the nursery beds indirectly help in increased multiplication of these endomycorrhizae providing tomato and egg plant seedlings with high colonisation of mycorrhizae which, in turn, could protect the crop from these nematodes to the maximum extent in the main field resulting in increased yields. Efficacy of these treatments was always compared with

carbofruran 2.0 kg a.i./ha) treatments and these treatments have proved as effective as chemical treatment and in some cases better than chemical treatment.

Combinations of deep ploughing (up to 20 cm) and nursery bed treatment with aldicarb at 0.4 g per m^2 and main field treatment with aldicarb at 1 kg a.i./ha proved effective in the control of root-knot nematodes in tomato which also registered maximum yield (Jain and Bhatti, 1985).

In tomato, application of aldicarb and carbofuran each at 1 kg a.i. per ha in combination with neem cake and urea each at 10 kg N per ha, at transplanting, produced maximum yield with lowest gall index (2.5) and nematode population, 90 days after planting (Routaray and Sahoo, 1985).

Zaki & Bhatti (1991) also found that integration of *P. lilacinus* and castor leaves was effective in increasing the growth of tomato and reducing the infestation by root-knot nematodes. Management of *M incognita* and *R. reniformis* in nursery beds to get healthy seedlings was attempted by integrating soil solarisation and oil cake (Mahua cake) incorporation.

Integrated control of plant parasitic nematodes on potato was attempted by the combinations of organic amendments, nematicide and mixed cropping with mustard (Akthar and Alam, 1991).

Integration of *P. lilacinus* and carbofuran at 2 kg a.i. per ha has proved to be effective in the management of reniform nematode, *R. renifonnis on* brinjal (Parvatha Reddy and Khan, 1989). Inoculation of endomycorrhizae–*Glomus mosseael G. jasciculation* in the nursery beds and subsequent application of 5% aqueous extracts of neem cake/castor cake/neem leaf/calotropis leaf in the nursery beds resulted in the effective management of root-knot and reniform nematodes in the nursery beds and yielded healthy brinjal seedlings which could withstand the attack of these nematodes after transplanting in the mainfield (Rao *et al.*, 1993).

Application of extracts of neem cake/neem leaf with spores of *P. lilacinus/V chlamydosporium* in the nursery beds and subsequent root-dip treatment in the above botanicals with the spores of bio-agents protected brinjal in the main field from the attack of root-knot and reniform nematodes. All these treatments significantly increased the yield under field conditions (Rao *et* al., 1993a).

An integrated management of root-knot nematodes, *M. incognita* infecting okra using neem or karanj oil cake at 0.5 ton per ha along with carbofuran at 1 kg a.i. per ha

was achieved. The above treatments gave maximum reduction in root galling with consequent increase in okra fruit yields (Parvatha Reddy and Khan, 1991).

Conclusions

The nature and magnitude of important diseases of vegetable crops caused by nematodes and their management has been reviewed. Information on historical highlights, economic importance and histopathological aspects has been provided. The role of nematodes in inducing complex plant diseases in association with other pathogens such as fungi, bacteria and viruses has been emphasised. Management of nematode diseases by host resistance and by suppression of nematode populations through physical, cultural, chemical, biological and integrated methods has been thoroughly discussed. The aspects which needs emphasis in future are as follows:

1. Intensive and systematic surveys of vegetable crops should be conducted with the dual objectives of determining the incidence, prevalence and severity of such diseases and the geographical distribution of the nematode involved. This would go a long way in developing an advisory diagnostic service for the farmers.

2. Adequate emphasis should be given to studies on the biology and host-parasite relationship of major nematode pests, which may lead to formulation of control methods on sound basis.

3. Studies have to be carried out on biotypes and on intraspecific variation in nematodes already known to be of economic importance in horticultural production in India.

4. Techniques for precise determination of damage thresholds of populations and assessment of crop losses have to be standardised.

5. Work on disease complexes involving nematodes be intensified with adequate collaboration between nematologists and plant pathologists.

6. Research on the use of cultural methods such as deep summer ploughings, use of plastics, intercropping and crop rotations should be intensified.

7. The chemical control measures should be effective and also economical. The use of chemicals should therefore, be explored with a view to get a reasonable cost-benefit ratio.

8. There is a great need to develop varieties, which are resistant or tolerant to

nematodes. Varietal screening and subsequent breeding programmes should be intensified. Fundamental investigations in relation to biochemical and physiological basis of resistance may also be taken up.

9. Attempts should also be directed towards biological control. *Paecilomyces lilacinus, Verticillium chlamydosporium, Trichoderma harzianum, Pasteurea penetrans* and VAM fungi have been identified all over the world as potential biocontrol agents against plant nematodes. The possibility of using these bacteria and fungi as biocontrol agents against nematodes infecting vegetable crops should be explored.

10. Development of integrated nematode management strategies for vegetable crops should be taken up. Research on the use of cultural methods such as deep summer ploughings and minimal use of nematicides by nursery bed treatments, seed treatments, seedlings bareroot dip treatments should be evaluated.

References

Ahuja, S. 1983. Comparative efficacy of some nematicides against root-knot nematode, *Meloidogyne incognita* in tomato, okra, brinjal and cauliflower. Third Nematological Symposium. Himachal Pradesh Agricultural University, Solan, p. 43.

Akhtar, M. and Alam, M.M. 1991. Integrated control of plant parasitic nematodes on potato with organic amendments, nematicide and mixed cropping with mustard. *Nematologia Mediterranea,* **19:** 1691-171.

Alam, M.M., Kham, A.M. and Saxena, S.K. 1974. Reaction of some cultivated varieties of egg plant, pepper and okra to the root-knot nematode, *Meloidogyne incognita. Indian Journal of Nematology* **4:** 64-68.

Alam, M.M., Saxena, S.K. and Khan, A.M. 1973. Control of root-knot nematode, *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949 on tomato and egg plant with V.C. 13 and Basamid liquid as bareroot dip. *Indian Journal of Nematology* **3**: 154-156.

Alam, M.M., Saxena, S.K. and Khan, A.M. 1977. Influence of interculture of marigold and margosa with some vegetable crops on plant growth and nematode population. *Acta Botanica Indica,* **5**: 33-39.

Atwal, A.S. and Mangar, A. 1969. Repellent action of root exudates of *Sesamum orientate* against the root-knot nematode, *Meloidogyne incognita* (Heteroderidae: Nematoda). *Indian Journal of Entomology* **31:** 286.

Bajaj, K.L. and Mahajan, R. 1977. Phenolic constituents of tomato resistant and susceptible to *Meloidogyne incognita* (Kofoid and White) Chitwood. *Nematologia Mediterranea* **5**: 329-

333.

Balasubramanian, M. and Rangaswami, G. 1964. Studies on host range and histopathology of root-knot infections caused by *Meloidogyne javanica. Indian Phytopathology.* **17:** 126-132.

Brezeski, M.W. 1971. *Butschli. Zeszyty Prob. Post. Newk. Rolniczych.* **121:** 107-111.

Conroy, J.H., Green, Jr. R.J. and Ferris, J.M. 1972. *Phytopathology* **62:** 362-366.

Darekar, K.S. and Patil, B.D. 1981. Reaction of some cowpea varieties to rootknot nematode. *Indian Journal of Nematology* **11:** 83-84.

Dasgupta, D.R. and Seshadri, A.R. 1971. Races of the reniform nematode. *Rotylenchulus reniformis* Linford and Olivera. 1940. *Indian Journal of Nematology* **1***:21-24.*

Ganguly, S. and Dasgupta, D.R. 1981. Protein pattern in resistant and susceptible tomato varieties inoculated with the root-knot nematode, *Meloidogyne icnognita. Indian Journal of Nematology,* **14:** 189-196.

Gupta, D.C. and Mukhopadhyay, M.C. 1971. Effect of N, P and K on the rootknot nematode, *Meloidogyne javanica* (Treub) Chitwood. *Science and Culture,* **37**: 246-247.

Gupta, J.C. and Atwal, A.S. 1972. Biology and ecology of *Haplolaimus indicus* (Hoplolaiminae: Nematoda), 3. Influence of population density on tomato and citrus plants. *Proceedings of Xith International Symposium on Nematology.* Reading, U.K. p.26.

Handa, D.K. and Mathur, B.N. 1981. Control of root-knot of chillies with nematicides. *Second nematology Symposium,* Tamil Nadu Agricultural University, Coimbatore, p. 48.

Haque, M.M. and Gaur, H.S. 1985. Effect of multiple cropping sequences on the dynamics of nematode population and crop performance. *Indian Journal of Nematology.* **15:** 262-263.

Haseeb, A., Butool, F. and Pandey, R. 1988a. Influence of different initial population densities of *Meloidogyne incognita* on the growth and oil yield of *Ocimum basilicum* cv. French. *Indian Journal of Mycology and Plant Pathology.* **6:** 176-179.

Jain, R.K. and Bhatti, D.S. 1978. Bare root treatment with systemics for controlling root-knot nematode in tomato transplants. *Indian Journal of Nematology,* **8:** 19-24.

Jain, R.K. and Bhatti, D.S. 1981. Systemics as seed treatment for the control of *Meloidogyne javanica* in okra. *Second Nematology Symposium,* Tamil Nadu Agricultural University, Coimbatore, p. 44.

Jain, R.K. and Bhatti, D.S. 1983. Chemical control of *Meloidogyne javanica in* tomato through nursery bed treatment. *Third Nematology Sympium,* Himachal Pradesh Agricultural University, Solan, pp. 37-38.

Jain, R.K. and Bhatti, D.S. 1985. Effect of summer ploughing alone and in combination with some other effective practices on the incidence of root-knot nematode *(Meloidogyne javanica)* on tomato (Cultivar HS 101). *Indian Journal of Nematology,* **15:** 62.

Jain, R.K., Bhatti, D.S., Bhutani, R.D. and Kalloo, G. 1983. Screening of germplasm of some vegetable crops for resistance to root-knot nematode *Meloidogyne incognita. Indian Journal of Nematology,* **13:** 212-215.

Jensen, H.J. 1972. In *Economic Nematology* (J.M. Webster, ed.), Academic Press, New York, U.S.A., pp. 377-401.

Jones, F.C.E. 1961. The potato root eelworm *Heterodera rostochiensis* Woll. In India, *Current Science,* **30:** 187.

Kandasamy, K. and Sivakumar, C.V. 1981. Effect of *Meloidogyne arenaria on* the germination of chilli *(Capsicum annum* Linn.) seeds. *Second Nematology Symposium,* Tamil Nadu Agricultural University, Coimbatore, p.6.

Kanwar, R.S. and Bhatti, D.S. 1990. Yield performance of resistant and susceptible tomato cultivars in monoculture and related reproduction of *Meloidogyne javanica. International Nematology Network Newsletter,* **7:** 16-18.

Khan, A.M. 1969. *Final Technial Report.* Grant No. FG-IN-225, Project No. 17-CR-65-Aligarh Muslim Univ., Aligarh, India.

Khan, A.M., Saxena, S.K. and Siddiqi, Z.A. 1971a. Efficacy of *Tagetes erecta* in reducing root infesting nematodes of tomato and okra. *Indian Phytopathology* **24:** 166-169.

Khan, A.M., Saxena, S.K. and Siddiqui, Z.A. 1971b. Reaction of some cultivated and wild species of *Lycopersicon* and cucurbits to *Meloidogyne incognita* (Kofoid and White) Chitwood. *Indian Phytopathology,* **24:** 197-199.

Khan, A.M., Saxena, S.K., Siddiqi, Z.A. and Upadhyay, R.S. 1975. Control of nematodes by crop rotation. *Indian Journal of Nematology* **5:** 214-221.

Khan, F.A. and Khan, A.M. 1973. Studies on the reniform nematode, *Rotylenchulus reniformis* I. Host range and population changes. *Indian Journal of Nematology* **3**: 24-30.

Leela, N.K., Khan, R.M., Parvatha Reddy, P. and Nidiry, E.S.J. 1992. Nematicidal activity of essential oil of *Pelargonium graveoleus* against the root-knot nematode. *Meloidogyne incognita. Nematologia Mediterranea,* **20: 57**-58.

Mai, W.F., Bloom, J.R. and Chen, J.A. 1977. The Pennysylvania State University College of Agriculture, *Agri. Expt. Sta. Bull.* Pp. 815-864.

Masood, A. and Husain, S.I. 1976. Phenolic and ortho-dihydroxy phenolic changes and their role in the resistance and susceptibility of three tomato varieties to *Meloidogyne incognita. Indian Journal of Nematology,* **6:** 86-93.

McKeen, C.D. and Mountain, W.B. 1960. *Can. J Bot.* **38:** 789-794.

Mountain, W.B. and McKeen, C.D. 1965. *Can. J Bot.* **43:** 619-624.

Mountain, W.B. and Patrick, Z.A. 1959. *Can. J Bot.* **37:** 459-470.

Olthof, T.H.A. and Reyes, A.A. 1969. *J Nematol.* **1**: 21-22.

Parvatha Reddy, P. 1984. Efficacy of seed treatment with the nematicides for the control of *Meloidogyne incognita* infecting cowpea, French bean and peas. *Indian Journal of Nematology,* **14**: 3 9-40.

Parvatha Reddy, P. 1985a. Chemical control of root-knot nematodes infecting peas. *Indian Journal of Nematology,* **15**: 226.

Parvatha Reddy, P. and Khan, R.M. 1988. Evaluation of *Paecilomyces tilacinus* for the biological control of *Rotylenchulus reniformis* infecting tomato as compared with carbofuran. *Nematogia Mediterranea* **16**: 113-116.

Parvatha Reddy, P. and Khan, R.M. 1989. Evaluation of biocontrol agent *Paecilomyces tilacinus* and carbofuran for the management of *Rotylenchulus renfiromis* infecting brinjal. *Pakistan Journal of Nematology* **7:** 55-59.

Parvatha Reddy, P. and Singh, D.B. 1979. Control of root-knot nematode, *Meloidogyne incognita* on tomato by chemical bare-root dips. *Indian Journal of Nematology,* **9**: 40-43.

Patel, G.J., Shah, H.M. and Patel, D.J. 1979. Reaction of some tomato cultivars to root-knot nematode. *Indian Journal of Nematology* **9**: 60-61.

Potter, J.W. and Olthof, T.H.A. 1974. *Phytopathology* **64:** 1072-1081.

Prasad, K.S.K., Raj, D. and Sharma, R.K. 1983. Effect of planting time on *Meloidogyne incognita* infesting potato at Shimla Hills. *Third Nematology Symposium,* Himachal Pradesh Agricultural University, Solan, pp. 5-6.

Raj, D. and Gill, J.S. 1983. Reaction of some potato varieties to root-knot nematode *Meloidogyne incognita. Third Nematology Symposium.* Himachal Pradesh Agricultural University, Solan, pp. 27-28.

Ramakrishnan, C. and Balasubramanian, P. 1981. Control of *Meloidogyne incognita* in chilli *(Capsicum annum* L.) nursery with nematicides. *Second Nematology Symposium,* Tamil Nadu Agricultural University, Coimbatore, p.54.

Ramana, K.V. and Mohandas, C. 1988. Occurrence of potato cyst nematode, *Globodera pallida* (Stone, 1973) in Kerla. *Indian Journal of Nematology* **18:** 141.

Rao, M.S. and Parvatha Reddy, P. 1992. Prospects of management of root-knot nematode on tomato through the integration of biocontrol agents and botanicals. *Seminar on Current Trends in Diagnosis and Management of Plant Diseases,* Bangalore, p. 10.

Rao, M.S. and Parvatha Reddy, P. 1993. Interactive effect of *Verticillium chlamydosporium* and castor cake on the control of root-knot nematode on egg plant. In *Soil Organisms and Sustainability* (D. Rajagopal, R.D. Kale, K. Bano, eds.), pp. 114-118. Indian Society of Soil Biology and Ecology, Univ. of Agri. Sci., Bangalore.

Rao, M.S., Mohandas, S. and Parvatha Reddy, P. 1993. Management of reniform nematode on egg plant by integrating botanical (castor cake), mycorrhiza *(Glomus fasciculatum)* and bioagent *(Paecilomyces lilacinus). Golden Jubilee Symposium on Horticultural Research-Changing Scenario,* Bangalore, pp. 259-260.

Rao, V.R. and Singh, D.B. 1978. Chemical control of root-knot nematodes in okra with the aid of nematicides. *Indian Journal of Nematology* **35:** 151-154.

Reddy, D.D.R. and Seshadri, A.R. 1972. Studies on some systemic nematicides, II. Further studies on the action of thionazin and aldicarb on *Meloidogyne incognita and Rotylenchulus reniformis. Indian Journal of Nematology,* **2:** 182-190.

Reddy, D.D.R. and Seshadri, A.R. 1975. Elimination of root-knot nematode infestation from tomato seedlings by chemical bare-root dips or soil application. *Indian Journal of Nematology,* **5**: 170-175.

Renjhen, P.L. 1973. *History of Plant Quarantine and its functioning in India.* Govt. of India, Minist. of Agri. Directorate of PI. Prot. Quarantine and Storage, Faridabad.

Routaray, B.N. and Sahoo, H. 1985. Integrated control of root-knot nematode, *Meloidogyne incognita* with neem cake and granular nematicides on tomato. *Indian Journal of Nematology* **15**: 261.

Sen, K. and Dasgupta, M.K. 1981. Effect of rice hull ash on root-knot nematodes in tomato. *Tropical Pest Management,* **27**: 518-519.

Sethi, C.L., Nath, R.P., Mathur, V.K. and Ahuja, S. 1972. Interceptions of plant parasitic nematodes from imported seed/plant materials. *Indian Journal of Nematology.* **2**: 89-93.

Shafiee, M.F. and Jenkins, W.R. 1962. *PI. Dis. Reptr.* **46**: 472-475.

Sharma, N.K. and Sethi, C.L. 1976. Reaction of certain cowpea varieties to *Meloidogyne incognita and Heterodera cajani. Indian Journal of Nematology* **6:** 99-102.

Shetty, K.D. and Reddy, D.D.R. 1985b. Resistance in *Solanum* species to rootknot nematode. *Meloidogyne incognita. Indian Journal of Nematology* **15**: 230.

Shivakumar, C.V., Palanisamy, S. and Balasubramanain, M. 1977. Control of *Rotylenchulus reniformis* in tomato nursery. *Indian Journal of Nematology* **7:** 78-80.

Shivkumar, C.V., Palanisamy, S. and Naganathan, T.G. 1976. Persistence of nematicidal activity in seed treatment of okra with carbofuran and aidicarb sulfone. *Indian Journal of Nematology* **6:** 106-108.

Siddiqi, M.R. 1986. *Tylenchida-Parasites of Plants and Insects*, CAB Publications, 645 pp.

Siddiqi, Z.A., Khan, A.M. and Saxena, S.K. 1976. Nematode population and yield of certain vegetables as influenced by oil-cake amendments. *Indian Journal of Nematology* **6:** 179-182.

Siddiqi, Z.A., Khan, A.M. and Saxena, S.K. 1973. Studies on *Tylencharhynchus brassicae* II. Effect of temperatures and moisture on multiplication of nematode. *Indian Journal of Nematology* **26:** 139-147.

Singh, D.B., and Parvatha Reddy, P. 1981.Note on chemical control of root-knot nematodes infesting french bean. *Indian Journal of Agricultural Science* **51**: 534-535.

Singh, D.B., Parvatha Reddy, P., Rao, V.R. and Rajendran, R. 1981. Reaction of some varieties and selections of French bean to *Meloidogyne incognita. Indian Journal of Nematology.* **11**: 81-83.

Singh, D.B., Rao, V.R. and Parvatha Reddy, P. 1978. Evaluation of nematicides for the control of root-knot nematodes on brinjal. *Indian Journal of Nematology* **8**: 64-66.

Singh, R.S. and Sitaramaiah, K. 1966. Incidence of root-knot of okra and tomato in oilcake amended soil. *Plant Disease Reporter* **50**: 668-672.

Singh, R.S. and Sitaramaiah, K. 1971. Control of root-knot through organic and inorganic amendments of soil: Effect of saw dust and inorganic nitrogen. *Indian Journal of Nematology* **1**: 80-84.

Singh, D.B. and Parvatha Reddy, P. 1982. Chemical control of *Meloidogyne incognita* infecting cowpea. *Indian Journal of Nematology,* **12**: 196-197.

Sivakumar, C.V. and Meerazainuddin, M. 1974. Influence of N, P and K on the reniform nematode, *Rotylenchulus rneiformis* and its effect on the yield of okra. *Indian Journal of Nematology* **4**: 243 -244.

Thakar, N.A. and Patel, C.C. 1985. Control of root-knot nematode, *Meloidogyne javanica* on tomato by chemical bare-root dips. *Indian Journal of Nematology* **15**: 110-111.

Thangaraju, D. 1983. Distribution of potato cyst nematodes in Kodaikanal Hills, Madurai district, Tamil Nadu, *Indian Journal of Nematology* **13**: 222-223.

Varma, M.K., Sharma, H.C. and Pathak, V.N. 1978. Evaluation of systemic granular nematicides against *Tylenchorhynchus* spp. Parasitic on cabbage. *Indian Journal of Nematology,* **8**: 59-60.

Zaki, F.A. and Bhatti, D.S. 1991. Effect of castor *ricinus communes* and the biocontrol fungus. *Paecilomyces lilacinus on Meloidogyne javanica. Nematologica,* **36**: 114-122.

❑❑❑

3

Management of Cereal Cyst Nematode, *Heterodera avenae* in Cereals

Indra Rajvanshi and G.L. Sharma

Introduction

Wheat is an extensively grown staple crop of India. Wheat and barley both are the major cereal crops in Rabi season and these occupy an unique position as a human diet, cattle. feed, fodder as well as the barley also be used in malt industry in India. In Rajasthan wheat is cultivated in about 25 lac ha whereas barley covers about 2.5 lac ha area. About 30 phytonematode species are found to be associated with these cereal crops. Of these, only *Heterodera avenae* & *Angunia tritici* are considered to be of major importance. Cereal cyst nematode (*H. avenae*) is considered to be the most important nematode infecting barley and wheat on a worldwide basis. This pest has been reported from 31 countries (Griffin, 1984), of which mainly are USSR, Canada, Australia, India and Pakistan.

Cereal cyst nematode, *H. avenae* was first recorded as a parasite of cereals in Germany by Kuhn (1874) and named as *H. schachtii*, which later on named as *H. avenae* by Wollenweber, (1924). In India, it causes a serious disease locally known as 'Molya', widely prevalent in Punjab, Rajasthan, Haryana, Himachal Pradesh, Uttar Pradesh, Madhya Pradesh, Jammu & Kashmir and Delhi states. In Rajasthan, 15 wheat/ barley growing districts having lighter soils are affected by the cereal cyst nematode. In India the *H. avenae* was first reported from Sikar district of Rajasthan (Prasad *et al.*, 1959). Of the 32 districts in the state, about 15 districts (Ajmer, Alwar, Bhilwara, Dausa, Hanumangarh, Jaipur, Jhunjhunu, Nagaur, Pali, Rajsamund, Sawaimadhopur, Sikar, Sirohi, Tonk and Udaipur) have shown the presence of molya disease of wheat and barley incited by *H. avenae*. The host range of CCN is limited to graminaceous plants (wheat, barley, oat and grasses).

Disease Influence

The incidence of the disease caused by CCN is dependent on many environmental factors. These factors influence both the parasite and the host plant in relation to disease production. In the parasite, the influence of these factors is manifested in processes like survival, hatching and emergence of larvae from cysts as well as the penetration and development of the nematode. With respect to the host, these factors govern the degree of damage done by nematode attack (Mathur, 1969).

Damage to crop is governed by soil moisture, soil texture, environmental factors, inoculum level and age of the host root. In adequately irrigated fields the number of larvae must be larger than in poorly irrigated fields to cause equal damage to host crops. High soil moisture content of the soils modifies host parasite interaction in such a manner that a better plant growth is obtained in spite of higher nematode multiplication. A positive correlation exists between the degrees of infestation of the CCN and crop damage. The relationship between yield and nematode population density varies with the host plants. In well-aerated soils, the multiplication of nematode and subsequent damage is more than in poorly aerated compact soils. Penetration of the larvae takes place mainly in the first four weeks reaching a peak in the third week in the roots (Mathur, 1969).

Crop Losses

Mathur (1969) estimated 40-50 per cent avoidable losses due to *H. avenae* in light sandy soils of Rajasthan. The disease is known to cause heavy damage in cereals in Rajasthan van-Berkum and Seshadri (1970) estimated a loss of 255 lakh rupees is in barley cultivated in Rajasthan. In severe infested fields, the total crop failures have also been observed (Swarup and Singh, 1961). Mukhopadhaya *et al.* (1972) reported that 10 cysts per kg soil caused about 10 per cent loss in wheat and barley yield, and the loss reached up to 64 per cent with 1,250 cysts in pots. Handa *et al.* (1985 a, b) reported avoidable losses to the extent of 87.2 per cent in grain and 91.8 per cent in fodder of barley at 22.41/g soil population level. These losses depend mainly on the CCN infestation level, soil texture, moisture, temperature, aeration, pH, osmotic pressure and also on the presence of micro-organism in the soil. Annual losses of about Rs.4 crore in wheat and that of Rs.1.5 crore in barley in Rajasthan state alone have been reported (Seshadri and Gupta, 1980; Bhatti *et. al.*1981b). They observed that molya infested fields treated with chemicals, yielded 8.9 to 95.3 per cent more than untreated control, depending upon initial nematode population density. Rajvanshi and Sharma (2002) have

studied the yield status and its declination (4.64%-59.45%) pattern in barley due to *H. avenae* (0.6-15.2l/gsoil) in light sandy soils.

Management

Cultural Practices

Crop Rotation

By growing a non-host crop in between two susceptible ones the population level of nematode is brought down below the damaging threshold. Handa (1983) experimented using non-host crop and fallowing, found that the nematode population decrease by 70 per cent with continuous rotation with non-host and increases by 87 per cent. He observed that yield of barley increased 56 per cent with two years rotation of non-host crops where as it decreased 35 per cent with susceptible barley. Under field condition barley C.V. Rajkiran reduced the cyst population to the 84.8 per cent (Singh and Yadav, 1986). The crop rotation with gram, mustard, carrot, radish, fenugreek and onion reduced the CCN population by 47-55 per cent in one crop season. Being host specific, it attacks only on wheat, barley and oat crops, therefore, growing of non-host crops or leaving the infested field fallow, showed a net reduction of CCN population up to 75 per cent after two years. A cultivation of susceptible wheat / barley with same field (Monocropping) increases the CCN population by 162-180 per cent (Mathur, 1969; Mathur and Handa, 1984). Singh *et al.* (1987) reported that mustard, toria, raya and taramira for one season resulted in 87-100 per cent reduction in cyst population.

Summer Ploughing/Solarisation

Deep summer ploughings under Indian conditions have their own advantages. The 2-4 deep summer ploughings in the months of May and June at the intervals of 10-15 days, reduced the CCN population at 40 per cent in one crop season. Stapleton and Devay (1983) in California found that solarisation resulted in the reduction of *Meloidogyne, Heterodera, Pratylenchus, Criconemella* and *Xiphinema* species and improved plant growth. Haque and Prasad (1981) observed that increase in the number of summer ploughings (three times before crop sowing) resulted in a corresponding decrease in population of *Hoplolaimus indicus, Helicotylenchus* sp., *Tylenchorhynchus vulgaris, Pratylenchus zeae* and *Longidorus* sp. and a corresponding increase in yield of wheat and barley during Rabi season. Handa (1983) investigated that 3 to 5 summer ploughings will bring down the initial CCN population and subsequently an increase in yield of wheat and barley crops. However, it should be ensured that there is no possibility of soil erosion

in the field with the turning of the soil during summer. The fallowing in Kharif Season or growing of non-host crops like Bajra, Groundnut does not have any effect on CCN population of the field. The field population of CCN in field is found to be increased in April (soon after crop harvest) then that of sowing period (November month) (Handa *et al.*, 1975; Mathur *et al.*, 1983 & 1987). Handa *et al.* (1975) indicated a decrease in the nematode population under conditions where soil was kept exposed by ploughing to direct sun heat during May- June in barley. Mathur *et al.* (1987) studied the effect of 1-5 deep summer ploughings at 7-10 days intervals in May-June months. Population reduction of nematode and increase in wheat yield was found to be directly proportional to the number of ploughings. A population reduction of 9.3-42.4 per cent and yield increase of 4.4- 97.5 per-cent were recorded.

Effect of Inorganic Fertilizers and Organic Manures

Among the major N.P.K. based inorganic fertilizers, only nitrogen application was observed to increase the level of phytonematodes as well as wheat and barley yield. The application of oil cakes, farmyards manure, saw dust and compost in infested soil improved plant growth and able to reduce the multiplication of the nematode (Mathur, 1969; Sakhuja, *et al.*1978; Mathur and Handa, 1984).

Mixed Cropping

Handa *et al.* (1980a) studied the effect of mixed sowing of resistant barley cv. Rajkiran with susceptible wheat cv. Kalyan Sona 50:50. The yield increased significantly and cyst population decreased in mixed sowing than susceptible wheat alone.

Date of Sowing

The early sowing of wheat in Haryana and Rajasthan conditions showed to be better yielder in CCN infested field.

Bhatti et *al.* (1980) found that the wheat sowing in nematode infested fields in early November yields more than late sown crop in India. Contrary to these results, Mathur and Handa (1984) suggested that altering the date of sowing did not influence the incidence of the disease and eel multiplication. If sufficient moisture is not available to allow hatching and wheat sowing is delayed, whole of the nematode inoculum will be available at sowing to infect the crop. Therefore, the disease severity and final nematode population may be similar at differ sowing date, where a sufficient moisture is available for larval hatching and emergence from cyst, and sowing is delayed (Brig Bhan and Kanwar, 2003).

Irrigation

Mathur *et al.* (1981) found that the multiplication of CCN was more in adequately irrigated fields of wheat than rainfed or unadequately irrigated fields.

Soil Amendments

Population reduction of nematode and increase in wheat yield was found to be directly proportional to organic amendments in addition to their suppressive effect on nematode densities, improved soil structure and water holding capacity, which improved the plant growth and yield. Mukhopadhyaya *et al.* (1972) managed the *H. avenae* by using mustard and castor cakes with significant improvement in the yield of wheat and barley. Mishra (1974) reported the effect of eight oil cakes (*Karanj, neem,* mahua, mustard, groundnut, cotton, linseed and sesamum) on various nematodes attacking various crops like wheat, mung bean and tomato etc. All cakes excepting linseed and cotton were found effective in reducing nematode population, and of these, the result of neem cake was found to be the best. These cakes were also found to possess residual effect and increased the plant growth and reduced nematode population in the next crops. Poultry manure was also effective in reducing nematode population and increasing plant growth parameters. It was reported to be effective due to high percentage of N and P content. Dhawan and Kaushal (1988) showed reduction in hatching incidence of *H. avenae* larvae by using of neem emulsion. Kaushal (1993) showed that neem powder and neem based chemicals found effective against *H. avenae*. Rajvanshi and Bishnoi (1998) observed decomposed leaves of neem, datura and aak on cereal cyst nematode in barley. They noted that the neem compost at 12 per cent was effective as compared to other treatments and decrease of cysts per plant.

Rajvanshi *et al.* (2001) observed the reduction in cyst population with the seed coating of carrot seed powder and turmeric powder @ 12 per cent in the infested field condition yielded significantly higher grain yield of barley. The experiment on management of cereal cyst nematode using oil cakes of neem, mustard, caster, cotton, til, wood saw dust (Babool) and vermicompost in CCN infested field in barley (RD-103) along with treated and untreated check. Neem cake was found more effective in increasing crop grain and reducing number of cysts per plant as compared to that of other oil cakes etc. (Rajvanshi and Bishnoi, 2002).The reduction in population of *H. avenae* in organic amended soil and roots of wheat might be due to the release of fatty acids, phenoliic compounds, ammonia and/or formaldehyde which are directly toxic to nematodes.

Intercropping

The intercropping treatments of mustard, carrot, fenugreek and reddish in CCN infested field with barley (RD 103) crops, gave significantly higher grain and fodder yield and reduced number of cysts/plant over control. (Rajvanshi *et al.* 2002)

Breeding for CCN Resistance

Resistance is the major source of nematode control. The first evidence of existence of pathotype in *H. avenae* was presented by Nilson-Ehle (1908). The search for nematode resistance in barley was also apparently initiated by Nilson-Ehle (1920) in Sweden and reported resistance in Primus, Schwannhals and Chevalier. Andersen (1959) recognised when he found that some of its population occurring differed in pathogenicity on barley variety. A single dominant gene is responsible for resistance in Loros spring wheat (Cook and McLeod, 1980). Deployment of genetic sources *viz.* (Marocaine, Morocco, C164 and PL101) for CCN resistance breeding assists in achieving yield stabilising in the CCN problematic areas without resorting to potentially harmful chemicals. At the same time it also prevent from environmental degradation and to benefit the resource poor farmers, because of the use of costly chemicals is beyond their reach. Sustainable barley production based on sound ecological principles, therefore, it currently becomes of increasingly importance.

Breeding for CCN resistance based on genetic principles was initiated at ARS Durgapura, Jaipur in mid-seventeen's after the discovery of resistance source for CCN in barley. Subsequently, its transfer in indigenous material, a first nematode resistant variety- Rajkiran (RDB-1/Marocaine) was developed through hybridisation followed by selection method .It is a dwarf, CCN resistant variety, developed and released in 1979 (Handa, 1992). This CCN resistance barley variety found highly susceptible to yellow rust as well as aphids and harvesting late due to late maturity, hence it did not widely accepted by the state farmers. Later on, two more high yielding CCN resistance and early maturing barley varieties (RD 2052 and RD 2035) were developed and got released in 1991. Its yield potential is 60-70 q/ha under high management conditions and is recommended for irrigated areas and soils having cereal cyst nematode infestation. Another second high yielding variety RD 2035 (Handa 1992) was developed and released in 1993.

A CCN resistance barley variety RD 2508 (RD 2035 P490) has been developed in 1996 from Rajasthan Agricultural University, Agricultural Research Station, Durgapura, Jaipur (Rajvanshi and Sharma, 2003).

For the evolution cereal cyst nematode (*H. avenae*) resistant wheat cultivars, the identification of the thousands of exotic and indigenous collections, commercial and improved strains and CCN resistant genotypes of wheat received from Europe and Australia were screened continousely for more then two decades. Of these, the AUS-15854 a bread wheat genotypes from Turkey, has exhibited resistance to majority of CCN populations of Rajasthan for several years. It has also given CCN resistant reactions at various ICAR centres *viz.* Delhi, Hissar, Durgapura and Karnal. While coming across the breeding programme, this genotype (AUS-15854) was used as a donor parent and crossed with seven varieties of higher agronomic traits (*viz.* J-24, HD-2009, HD-2329, RAJ-2184, RAJ-2535, RAJ-3077 and Kalyan Sona). As a result of hybridisation (F_1- F_6) seven lines were developed *viz.* CCN RV-1, CCN RV-2, CCN RV-3, CCN RV-4, CCN RV-5, CCN RV-6 and CCN RV-7. Of which on the basis of CCN resistant grain yield quality and agronomic traits, the CCN RV-1, CCN RV-3, CCN RV-7 were selected for cultivators use (Mathur *et al.*, 1998; Sharma & Sharma, 2000). The CCN resistant wheat variety Raj MR-1 was released for cultivation of wheat infested field for molya disease from Agricultural Research Station, Durgapura, Jaipur for the state of Rajasthan.

Integrated Pest Management

It is pest management system that in the context of associated environment and population dynamics of the pest species, utilises all suitable techniques and methods in as compatible manner as possible and maintains pest populations at level below those causing economic injury. It is not the superposition of two management techniques but the integration of all suitable management techniques with natural regulating and limiting elements of the environment. Integrated Pest Management (IPM) is a multidisciplinary approach which includes all pest management practices. IPM consists of the development, use, and evaluation of pest control strategies that result in favourable socio-economic and environmental consequences (Bird 1980; Chakraborti 2001). IPM can be divided into seven components: biological monitoring, environmental monitoring, decision-maker, decision support system, the decision, procedure implementation, and the system (Fig-1).

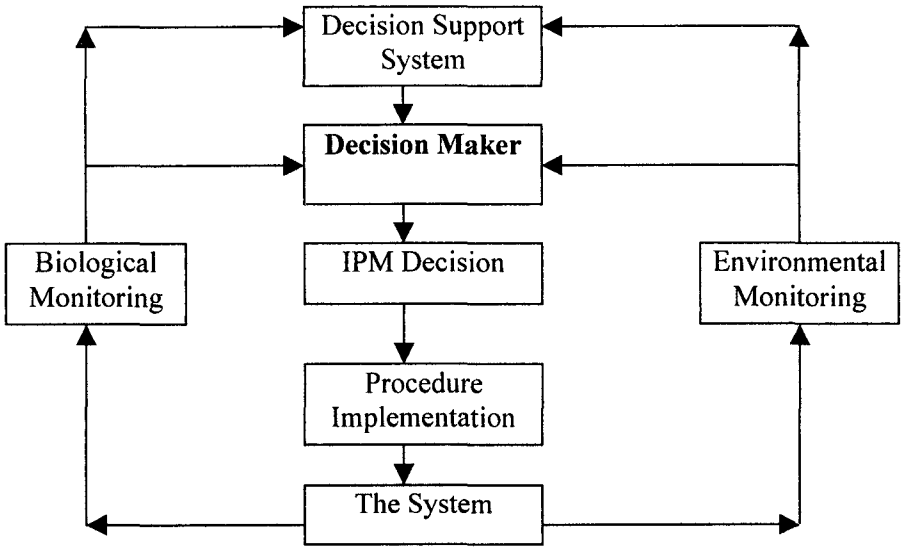


Fig. 1. The components used in integrated pest management programme.

Integrated Nematode Management (INM)

Summer Ploughing with Chemicals

A combined treatment of deep summer ploughings with Aldicarb/carbofuran @1.0 Kg a.i /ha proved better grain yield and reduction in CCN population than that of unploughed and chemical treatment alone (Mathur *et al.*, 1984). The drill application of carbofuran 3G @ 1.5 kg ai/ha with 90 kg N/ha, reduced CCN population (22-86%) and increased barley yield 65-95 per cent with economic B/C ration (Mathur, *et al.* 1984).

Use of Bioagent

When *Trichoderma viride* and reduced dose of Carbofuran (0.75 kg ai/ha) along with compost were used in wheat, found to reduce the CCN population and increase in the grain yield (Pankaj *et al.*, 2002). The integrated approach of bioagent (*T. viride*), compost and reduced dose of carbofuran were able to minimise the development of nematode and also gave better grain and fodder yield as compared to untreated check in wheat (Rajvanshi, 2003). *T. viride* is already known for the production of antibiotic substances like 'gliotoxine' and 'viridin' which have been accounted for control of soil-born diseases (Brain and McGowan, 1945). Probably these antibiotics together with other metabolic products might be responsible for inhibiting the hatching of nematode. Rajvanshi and Sharma (2005) observed that use of bioagents (*Beauveria bassiana* and

Metarhizium anisopliae) as a seed coat treatment (6g/kg seed) have also reduced the *H. avenae* population on barley and increased the grain yield.

Chemical Control

Chemicals that are being used for the management of plant parasitic nematodes are costlier and hazardous in nature. In the beginning the halogenated hydrocarbons *viz.* DD. @ 300 l/ha and DBCP @ 45 l/ha were found very efficient in reducing CCN population in wheat/barley fields (Handa *et al.*, 1980; Handa & Mathur, 1982). Later on the granular formulations *viz.* Phorate 10G, Aldicarb 10G, Carbofuran 3G, Fensulfothion, Tarbufos, Quinalphos, Disulfotan and Diazomet when applied as a pre-planting broadcast/drill applications were found to significantly increase the grain and fodder yield of wheat (Handa *et al.*, 1980; Handa & Mathur 1982). They found optimal economic dose for the use of Carbofuran is 1.5 Kg a.i /ha for wheat and 1.0 Kg a.i /ha for barley. The carbosulfan (Posse) 25 ST when used @ 1.0% (w/w) in barley as seed dresser against cereal cyst nematode, was found quite effective in reducing nemic population and increased grain yield of barley as compared of check (Rajvanshi and Bishnoi 1995). The use of Carbofuran, Sebufos, Achook and Padan found to be effective in reducing CCN population and increasing the grain yield level of barley crop (Rajvanshi and Sharma, 2000). Sharma and Rajvanshi (2004) have again concluded that a combination of chemicals along with biopesticides (Achook) reduced the CCN level and increased the grain yield of wheat.

References

Andersen, S. (1959). Resistant of barley to various population of the cereal root eelworm (*Heterodera avenae*). *Nematologica.* **4**: 91-98.

Bhatti, D.S., Dalal, M.R. and Malhan, I. (1981b). Estimation of loss in wheat yield due to the cereal cyst nematode, *Heterodera avenae. Tropical pest management.* **27**: 375-378.

Bhatti, D.S., Dalal, M.R., Dahiya, R.S. & Dhawan, S.C. (1980). Integrated control of *Heterodera avenae* in wheat. *J.Nematol.*, **12**: 214-215.

Bird, G.W. (1980). Nematology- Status and perspectives. The role of nematology in integrated pest management. *J. Nematology.* **12**: 170-176.

Brain, P.W. and McGowan, J.C. (1945).Viridin a highly fungistatic substances produced by *Trichoderma viride. Nature*, **156**: 144.

Brij Bhan and Kanwar, R.S. (2003). Effect of sowing time on multiplication of *Heterodera avenae* and performance of wheat crop. *Indian J. Nematol.*, **33** (2): 172-174.

Chakrabarti, U. (2001). Compatibility of neem products and neem formulation with systemic nematicides for the management of *Meloidogyne incognita* infecting chickpea. Ph.D. Thesis, IARI, N. Delhi.

Cook, R. and Mcleod, R.W. (1980). Resistance in wheat to *Heterodera avenae* in Australia and Britain. *Nematologica*, **28**: 274-277.

Dhawan, S.C. and Kaushal, K.K. (1988). Effect of neem emulsion on the hatching of cereal cyst nematode, *Heterodera avenae. Indian J. Nematol.*, **18** (2): 364.

Griffin, G.D. (1984). Nematode parasites In: *Plant Insect Nematodes* (ed. Nickle, W.R.) pp. 243-321. Marcel Dekker Inc. New York and Barel.

Handa, D. K. (1983). Studies on molya disease (*Heterodera avenae* woll.) of wheat barley with special emphasis on its control. Ph.D. Thesis Univ. of Rajasthan. 340 pp.

Handa, D.K. (1992). Management of cereal cyst nematode (*Heterodera avenae)* in barley. In: *Recent Advances in Nematology*. 83-99 pp.

Handa, D.K.; Mathur, B.N., Sharma, G.L. and Yadav, B.D. (1980a). Effect of mixed cropping on susceptible wheat& resistant barley on the control of molya disease. *Indian J. Mycol. & Plant Pathol.* **10** (2): VII.

Handa, D.K.; Mathur, R.L. and Mathur, B.N. (1975). Studies on the effect of deep summer ploughings on the cereal cyst nematode (*Heterodera avenae)* and yield of wheat and barley. (Abstr.). *Indian J. Mycol. and Pl. Pathol.* **5** (1): 18.

Handa, D.K.; Mathur, R.L.; Mathur, B.N. and Yadav, B.D. (1985a). Estimation of losses in barley due to cereal cyst nematode in sandy and sandyloam soils. *Indian J. Nematol.*, **15**: 163-166.

Handa, D.K.; Mathur, R.L.; Mathur, B.N.; Sharma, G.L. and Yadav, B.D. (1985b). Host efficiency of tall and dwarf wheat and barley crops of cereal cyst nematodes (*Heterodera avenae). Indian J. Nematol.,* **15**: 30-42.

Haque, M.M. and Prasad, D. (1981). Effect of agronomical practices and D.D. and application on nematode population and crop yield (Abstr.). *Indian J.Nematol.*, **11**: 124.

Kaushal, K.K. (1993). On the effectiveness of 'neem' products against the cereal cyst nematode *Heterodera avenae. Indian J. Nematol.*, **23** (2): 218-219.

Kuhn, I. (1874). Uber das Vorkommen Von Rubennematoden an den wurzelnder Halmfruchte, *Landw, Jbr.* **3**: 47-50.

Mathur, B.N. (1969). Studies on cereal root eelworm (*Heterodera avenae* Woll) with special reference to 'Molya' disease of wheat and barley in Rajasthan. Ph.D. Thesis, University of Rajasthan, 233 pp.

Mathur, B.N., Arya, H.C., Handa, D.K. and Mathur, R.L. (1981). The biology of cereal cyst nematode, *Heterodera avenae* in India III. Factor affecting population level and damage to host crops. *Indian J. Mycol. And Pl. Pathol.* **11** (1): 5-13.

Mathur, B.N. and Handa D.K. (1984). Cultural practices and their effects on cereal cyst nematode and yield of wheat in Rajasthan, India. First Internation Congress of Nematology, Guelph, Ontario, Canada, Aug. 5-10: 62 p. (Abstract).

Mathur, B.N. and Handa D.K. and Swarup, G. (1983). Fourth Int. Congr. Pl. Path. Melbourne, Australia, Aug. 17-24. (Abst.).

Mathur, B.N., Handa, D.K., Sharma, G.L. and Yadav, B.D. (1984). Cultural pratices and their effects on cyst nematode and yields of wheat in Rajasthan, India. First Internation Congress of Nematology, Guelph, Ontario, Canada, Aug. 5-10: 62 p. (Abstract).

Mathur, B.N. and Handa, D.K. and Swarup, G. (1987). Effect of deep summer ploughings on the cereal cyst nematode, *Heterodera avenae* and yield of wheat in Rajasthan, India. *Indian J. Nematol.*, **17**: 292-295.

Mathur, B.N., Bhatnagar, V.K., Sharma, S.N. and Sharma, G.L. (1998). Evaluation of CCN resistant wheat variety for higher yield. IIIrd International Symposium of Afro-Asian Society of Nematologists. April 16-19: (Combatore).

Mishra, S.D. and Prasad, S.K. (1974). Effect of oil amendments on nematodes and crop yield. *Indian J. Nematol.*, **4**: 1-19.

Mukhopadhyaya, M.C.; Dalal, M.R.; Saran, S. and Kharub, S.S. (1972). Studies on the 'Molya' disease of wheat and barley. *Indian J. Nematol.*, **2**: 11-20.

Nilson-Ehle, H. (1908). Om Olike augrepp af hafreaten (*Heterodera Schachtii)* pa olike kornsorter, *Sveriges Utsadesforwings Tidskrift* **18**: 171-173.

Nilson-Ehle, H. (1920). Uber Resistenz gegen *Heterodera Schachtii* bci geursses Gerstensorten ihre Vererburgswerise and Bedentung far die Praxis. *Hereditas.* **1**: 1-34.

Patel, R.G. and Patel, D.J. (1992). Comparative of some organic amendments and granular nematicides in the control of *Rotylenchulus reniformis* infecting pigeonpea. *Indian J. Nematol.*, **22** (1): 14-18.

Prasad, N.; Mathur, R.L. and Seghal, S. P. (1959). Molya disease of wheat and barley in Rajasthan. *Curr. Sci.* **28**: 453.

Rajvanshi, Indra and Bishnoi, S.P. (1995). Control of cereal cyst nematode through seed dressers in Barley. *Indian Wheat Newsletter ICAR* **1**: 5.

Rajvanshi, Indra and Bishnoi, S.P. (1998). Affects of decomposed leaves on cereal cyst nematode of barley. Third International Symposium of Afro-Asian Society of Nematologists. April 16-19, Comibatore, India.

Rajvanshi, Indra (2003). Integrated management of cereal cyst nematode, *Heterodera avenae* in barley. *Current Nematology* **14** (1, 2): 99-101.

Rajvanshi, Indra and Sharma, G.L. (2002). Declination of yield status of barley due to *Heterodera avenae* Woll. In light sandy soils of Rajasthan State. *Current Nematology.* **13** (1, 2): 27-29.

Rajvanshi, Indra and Bishnoi, S.P. (2002). Management of cereal cyst nematode, *Heterodera avenae* using various soil amendments in barley. *Journal Forage Science* **25** (2): 96-97.

Rajvanshi, Indra and Sharma, S.N. (2003). Breeding for resistance to cereal cyst nematode, *Heterodera avenae* in barley. *Current Nematology* **14** (1, 2): 25-26.

Rajvanshi, Indra and Sharma, G.L. ((2000). Management of Cereal Cyst Nematode, *Heterodera avenae* in barley through chemicals. *Current Nematology.* **11** (1, 2): 35-37.

Rajvanshi, Indra and Sharma, G.L. (2005). Bio-control of cereal cyst nematode, *Heterodera Avenae* in Barley using Bioagents. National Symposium on Recent Advances and Research Priorities in Indian. Nematology Society of India, held at IARI, New Delhi, from dated 9-10 Dec.: 62.

Rajvanshi, Indra; Mathur, B.N. and Sharma, G.L. (2002). Effect of Inter-cropping on incidence of, Heterodera *avenae* in wheat and barley crops. *Ann. Pl. Protec. Sci.* **10**: 406-407.

Rajvanshi, Indra; Sharma, G. L.; Chand Ramesh and Bishnoi, S.P. (2001). Management of *Heterodera avenae* through botanicals in wheat and barley. *Ann. Pl. Protec. Sci.*, **9**: 362-363.

Sakhuja, P.K.; Sing, I. and Sharma, S.K. (1978). Effect of nitrogen levels alone and on combination with some nematicides on the population of cereal cyst nematode, *Heterodera avenae* and yield of wheat. *Indian J. Nematol.*, **8** (3): 159-162.

Seshadri, A.R. and Dasgupta, D.R. (1980). In *Hand Book of Agriculture,* ICAR, New Delhi. 551-557pp.

Sharma, G.L. and Sharma, S.N. (2000). Evaluation of cereal cyst nematode (*Heterodera avenae*) resistant wheat variety in Rajasthan. *India Wheat Inf. Service.* **90**: 49-59.

Sharma, G.L. and Rajvanshi, Indra (2004). Management of Cereal Cyst Nematode, *Heterodera avenae* in wheat using chemicals and biopesticides. *Indian Journal of Environmental Sciences.* **8** (1): 53-54.

Singh, H. and Yadav, B.S. (1986). Proc. Nat. Conf. Plant Parasitic Nematodes of India-Problems & Progress. IARI, New Delhi. 490pp.

Singh, I.; Sakhuja, P. K. & Sharma, S.K. (1987). *Plant Dis. Res.* **2**: 93-94.

Stapleton, J.J. and Devay, J.E. (1983). Response of phytoparasitic and free living nematodes to soil solarisation and 1,3- dichloropropane in California, *Phytopathology,* **73**: 1426-1436.

Swarup, G. and Singh, K. (1961). 'Molya' disease of wheat and barley in Rajasthan. *Indian Phytopath.*, **14**: 127-133.

Van- Berkum, J.A. and Seshadri, A.R. (1970). Some important nematode problems in India (Abstr.) Xth International Nematology Symposium. Pescara. Italy: 136-137.

Wollenweber, H. (1924). *Zur Kenntis Der Kartoffel- Heterodera.* I 11.Landw.Ztg, No.1: p100-101.

Yayock, J.Y. and Awoniyi, J. O. (1974). Organic manures and industrial waste and chemical fertilization of maize and sorghum. *Samaru Agricultural Newsl.* **16**: 9-10.

❑❑❑

4

Root-knot Nematodes of Medicinal and Aromatic Plants and Their Eco-friendly Cost Effective Management

Rakesh Pandey

Introduction

The economic development of any country relies on optimisation of crop production, enhancement in the export and limitation on avoidable imports. The availability of nutritious and healthy food, disease controlling food supplements and therapeutics are, among several factors, the determinants of quality of life of people all around the world. In recent years traditional medicines, which is widespread in China, India, Japan, Pakistan, Sri Lanka and Thailand derived from plant sources is one of the important ways to support herbal medicine system for human health and care. For example in China about 40 per cent of total medicine consumption is attributed to traditional tribal medicine. The herbal medicine demand in Japan and other developed nations are very high. Similarly aroma compounds from botanical sources hold a promising field by being increasingly used in cosmeceutical, nutraceutical, food and flavour industries due to the growing awareness in common masses about the risks involved in synthetic components in parallel products. The plant retail market including herbs and medicinal plants in the US is estimated approximately US$ 1.6 billion annually. In European countries about 400,000 ton of medicinal plant material exported from Asia and Africa. The average market value of this plant material is US$1 billion. Therefore it is useful to say that the major raw materials used in pharmaceutical industries come from medicinal plants globally. Of late, farmers are more motivated to cultivate medicinal and aromatic plants (people in tropical and subtropical countries cultivate these crops as industrial cash crop) because these crops can be incorporated in various cropping systems and also generate significant income. The cultivation, processing and trade through value addition of materials come from these medicinal plants are providing much needed avenues of self-

employment. The business opportunities in the sector of medicinal plants are enormous and are visible on the rise due to the diversified uses that plant inhabited important molecules and compounds are finding in pharmaceutical, cosmeceutical, nutraceutical and agri chemical industries. In well-developed industrialised nations plant derived drug prescriptions become a major element in maintenance of human health. Therefore medicinal plants become an integral component of research in most of the pharmaceutical industries. Germany, Bulgaria and Poland becoming major exported of plant based medicinal products. It has also been estimated that Hong Kong, Germany, Japan and Singapore are the major importing countries in medicinal plant trade with estimated share of 17.3, 12.0, 10.2 and 8.4 per cent respectively. In concrete it was found that Europe become huge reservoir of global herbal market constituting about 45 per cent of total market followed by North America (18.2%) and Asia (18.2%) (Khanuja, 2003).

Root-knot nematodes constitute one of the most important groups of pathogenic organisms prevalent in and around the root playing a significant role in the plant growth and yield reductions. Undoubtedly, different root-knot nematode species are associated with most of the medicinal and aromatic plants and cause significant damage, but the magnitude of crop damage has been established in only a few medicinal and aromatic plants. Mostly two root-knot species (*Meloidogyne incognita* & *M. javanica*)) affect cultivation of major medicinal and aromatic plants. The major crops which suffer root-knot nematode infestation are: Menthol mint, Henbanes, Basil, Opium poppy, Aswagandha, Sarpgandha, Coleus, Kinghao, Brahmi and musli (Pandey, 1998b, Pandey, 2003; Koshy *et al.*, 2005). Some of the models and techniques have been suggested to avoid the economic loss caused by this pest to medicinal plants (Pandey, 1993, 1998b; Pandey *et al.*, 1992; Luc *et al.*, 2005).

The past few years have witnessed a steep rise in the cultivation area of medicinal and aromatic plants mainly because of higher net returns and greater demand in the world market. But at the same time the destruction caused by root-knot nematodes has increased tremendously in arable soil and this may be due to the continuous cultivation of nematode susceptible agricultural crops. Also the scope of chemical armory to combat with this pest has been decreased. The major reason behind this scenario is increased awareness about the adverse effect of chemical pesticides. They are highly important for agriculture, pest control, national health programmes *viz.* eradication of insect vectors of malaria, filarial, kalaazar, dengue fever and Japanese encephalitis, but the presence of these pesticidal chemicals in the environment produces biodegradation of

ecosystem and surreptitious long acting toxic effects on human health. Different pesticides effects almost all metabolic systems of human body like dermal, cardiac, respiratory, renal, hormonal, reproductive, gastrointestinal and central nervous system in particular, They are also implicated in mutagenesis and carcinogenesis. Therefore effective chemical nematicides for field use may not be available in the future. Consequently it has become inevitable to manage this pathogen through non-chemical methods. Though, several non-chemical management tactics like fallow, flooding, changes in time of sowing/planting material, tillage practices, crop rotations, use of antagonistic crop, trap crop/cover crop, use of nematode free planting materials or seeds, solarisation, organic amendment and biological control are available, efforts are directed towards the use of microbes to minimise the phytonematode population and to make soil more suppressive to nematode diseases (Sikora, 1992; Pandey; 1998b; McSoreley, 1998; Meyer and Roberts, 2002; Luc *et al.*, 2005). Different microbes have been exploited in this lab to reduce the population of phytonematodes below the economic threshold level (Pandey *et al.*, 2000) and could play a significant role either singly or can be integrated with other practices to develop integrated nematode management practices (INMP). Studies conducted at CIMAP, Lucknow so far indicate that microbial agents may play a significant role in limiting phytonematode population (Pandey *et al.*, 1997, 1999, 2000b). The results of the studies carried out on major medicinal plants like *Artemisia annua, Artemisia pallens, Bacopa monnieri, Chlorophytum borivillianum*, *Hyoscyamus* spp., *Lavandula officinalis, Mentha arvensis, Rauvolfia serpentina, Withania somnifera, etc.* have proven the efficacy of microbial agents (*Paecilomyces lilacinus, Glomus aggregatum, Trichoderma harzianum, Glomus fasciculatum, Glomus mosseae, Pseudomonas florescens* etc.) and organic farming in the management of nematodes and for sustainable growth and yield of medicinal and aromatic plants (Pandey *et al.*, 1997, 1999; 2000b).

Table 1: List of major medicinal and aromatic plants and their important constituents

S. No.	Botanical Name	Family	Biological Activity	Important Constituents
1.	*Aloe vera* (L.) Burm.f.	Liliaceae	Leaf-oxytocic, purgatives, antitubercular, antibacterial	C-glucosides,Volatile oil, resin, gum, emodin, anthraquinone derivative, Chrysophanic acid, Coumarins, Amino acids and sugars

2.	*Andrographis paniculata* Wall. Ex. Nees	Acanthaceae	Antityphoid, antifungal, hepatoprotective, antidiabetic, cholinergic,	Flavonoids, sesquterpenes, andrographolide, kalmeghin,
3.	*Apium graveolens* Linn.	Apiaceae	Tranquilizer, anticonvulsant, antifungal	Limonene, sabinene, aldehydes, terpenoids, coumarins, glycosides, polyphenols
4.	*Asparagus racemosus* Willd.	Liliaceae	Antirheumatic, anticancer, antibacterial, antifungal	Shatavarins I-IV, sarsapogenin, rutin, diosgenin, Cyanidin-3, 5-diglucoside, ferulic acid, caffeic acid, chlorogenic acid, sitosterol
5.	*Artemisia annua*	Compositae	Antimalaria	Arteether, Artemisinene
6.	*Artemisia pallens*	Compositae	Perfumery and cosmetics	
7.	*Atropa belladonna* L.	Solanaceae	Sedative, antispasmodic, stimulant, used in ophthalmology to dilate pupils	Hyoscine, hyoscyamine, atropine, flavonoglucosides-rutin, scopolamine,
8.	*Bacopa monnieri* (L.) Penn.	Scrophulariaceae	Herpestine, saponins, monnierin; hersaponin, bacoside A and bacoside B.	Baccoside, A & B, hespestine, Mannitol, saponins
9.	*Boerhavia diffusa* L.	Nyctaginaceae	eupalitin-3-O-beta-D-galactopyranoside), Bd-II (eupalitin)	Hypoxanthin-9-L-arabonofuranoside, hentriacontane, beta-sitosterol, ursolic acid
10.	*Centella asiatica* (L.) Urban	Hydrocotylaceae	Sedative, Tranquilizer, antiprotozoal, spasmodic, antileprotic	Asparatic acid, glycine, glutamic acid, alpha – alanine, phenylalanine, beta – sitosterol, brahminoside, brahmic acid, stigmasterol, vellarine

11.	*Curcuma domestica* Valeton syn. C. longa L.	Zingiberaceae	Anti-inflammatory, antiprotozoal, spasmolytic, antiarthritic, antihepatotoxic	Turmerone, ar-turmerine, sabinone, curlone, curcuminoids, stigmasterol,
12.	*Digitalis purpurea* Linn.	Scrophulariaceae	Dioxin, antifungal	Glucosides digitoxin, gitoxin
13.	*Glycyrrhiza glabra* Linn.	Fabaceae	Antidiuretic, anti-inflammatory, antiarthritic, expectorant, antiulcerous, antihistamine	Glycyrrhizin, glucose, sucrose, mannite, starch, asparagines, resin
14.	*Hyoscyamus niger* L.	Solanaceae	Antispasmodic	Hyoscine, hyoscyamine, atropine
15.	Mentha arvensis L.	Lamiaceae		Menthol, menthyl acetate, menthone, terpenes
16.	*Matricaria chamomilla* L syn. M. recutita	Asteraceae		Flavonoids, glucosides, bisabosoidesmatricin, prochamazulene
17.	*Ocimum basilicum* Linn.	Lamiaceae	Antibacterial, antifungal	1,8-cineole, eugenol, limonene, geranial, citronellol, linalool, methylchavicol
18.	*Papaver somniferum* Linn.	Papaveraceae	Analgesic, decrease blood pressure, spasmolytic, antiprotozoal, anticancer	Papaverine, codeine, morphine, thebaine, narcotine, narceine, codamine, etc.
19.	*Rauvolfia serpentina* (L.) Benth.ex. Kurz	Apocynaceae		Reserpine, ajmalicine, ajmaline, sarsapogenin
20.	*Withania somnifera* (L.) Dunal	Solanaceae	Anti-inflammatory, antiasthamatic, antitumor, antispasmodic	Withanolides, Tropine. Pseudotropine, choline, cucohygerine, anaferine, anahygrine

Table 2: List of medicinal and aromatic plants affected with *Meloidogyne incognita* and *M. javanica*.

S. No.	Name of Plant	Family	*M.incognita*	*M. javanica*
1.	*Abelmoschus moschatus* (L.) Medik	Malvaceae	++++	++
2.	*Abutilon indicum* (L.) Sweet	Malavace	++	++
3.	*Achyranthes aspera* (L.)	Amaranthancae	++	++
4.	*Acorus calamus* (L.)	Araceae	-	++
5.	*Adhatoda vasica* Nees	Acanthaceae	+++	+++
6.	*Aloe barbadensis* Mill.	Liliaceae	++	++
7.	*Aloe peryii* Baker	Liliaceae	+++	++
8.	*Alpinia galanga* (L.) Sw.	Zingiberaceae	-	++
9.	*Ammi majus* (L.)	Apiaceae	+++	++
10.	*Ammi visnaga* Lamark	Apiaceae	+++	+++
11.	*Andrographis paniculata* (Burm. F.) Wall ex Nees	Acanthaceae	++	-
12.	*Apium graveolens* (L.)	Apiaceae	++	+++
13.	*Argyreria speciosa* Sweet	Colvolvulaceae	+++	
14.	*Artemisia annua* (L.)	Compositae	+++	-
15.	*Artemisia pallens* Wall ex. DC	Compositae	++++	++
16.	*Aslepias curassavica* (L.)	Asclepiadaceae	+++	++
17.	*Asparagus racemosus* Wild	Liliaceae	++	+++
18.	*Atropa belladona* (L.)	Solanaceae	++	-
19.	*Bacopa monnieri* (L.) Penn.	Scrophulariaceae	++++	-
20.	*Berringtonia acutangula* (L.) Gaertn.	Lecythidaceae	++	++
21.	*Boerhavia diffusa* (L.)	Nyctaginaceae	++	++
22.	*Callistemon citrinus* Skeel	Myrtraceae	++	
23.	*Callistemon lanceolata* DC.	Myrtraceae	+++	++
24.	*Calotropis procera* Br.	Asclepiadaceae	-	-
25.	*Calotropis gignatea*	Asclepiadaceae	++	++
26.	*Cassia angustifolia* Vahl.	Fabaceae	++	++
27.	*Catharanthus albus* (L.)	Apocynaceae	+	-
28.	Catharanthus roseus (L.)	Apocynaceae	++	

29.	Celastrus paniculatus Wild.	Celastraceae	+	++
30.	Clitoria ternatea (L.)	Fabaceae	++	++
31.	Coleus aromticus Benth.	Laminaceae	+++	++++
32.	Commiphora wightii Jacq.	Burseraceae	++	++
33.	Coriandrum sativum (L.)	Apiaceae	+++	++
34.	Costus specious (Koen.) Sm.	Zingiberaceae	++	-
35.	*Crateva nurvala* Buch. Ham	Capparaceae	++	++
36.	*Curcuma amada* Roxb.	Zingiberaceae	++	-
37.	*Curcuma longa* Auct. non.(L.)	Zingiberaceae	-	++
38.	*Datura metel* (L.)	Solanaceae	++	-
39.	*Dathura stramonium* (L.)	Solanaceae	-	++
40.	*Desmodium gangeticum* (L.)DC.	Fabaceae	+++	+++
41.	*Digitalis lanata* (L.)	Scrophulariaceae	+++	++
42.	*Digitalis purpurea*	Scrophulariaceae	+++	-
43.	*Dioscorea composita* (L.)	Dioscoreaceae	++	-
44.	*Dioscorea floribunda* (L.)	Dioscoreaceae	++	++
45.	*Elytaria acualis* (L.P) lind	Acanthaceae	++	++
46.	*Hemidesmus indicus* (L.) R.Br.	Asclepiadaceae	++	++
47.	*Hygrophila auriculata* R. Br.	Asclepiadaceae	++	++
48.	*Hyoscyamus albus* (L.)	Solanaceae	++++	++
49.	*Hyoscyamus muticus* (L.)	Solanaceae	++++	++
50.	*Hyoscyamus niger* (L.)	Solanaceae	++++	++
51.	*Indigofera tinctoria* (L.)	Fabaceae	++	++
52.	*Ipomoea hederacea* (L.) Jacq.	Convolvuaceae	++	-
53.	*Ixora coccinea*	Rubiaceae	++	+
54.	*Jasmine humile* (L.)	Oleaaceae	-	++
55.	*Lactuca sativa* (L.)	Asteraceae	++	++
56.	*Lepidum sativum* (L.)	Brassicaceae	++	++
57.	*Malva sylvsetris* (L.)	Malvaceae	-	-
58.	*Melissa officinalis*	Lamiaceae	+++	++
59.	*Matricaria chamomilla* (L.)	Asteraceae	+++	-
60.	Ocimum basilicum (L.)	Lamiaceae	+++	+++

61.	Ocimum canum (L.)	Lamiaceae	+++	++
62.	Ocimum gratissimum (L.)	Lamiaceae	+++	++
63.	Ocimum kilmandscharicum (L.)	Lamiaceae	++	++
64.	Ocimum santum (L.)	Lamiaceae	++	++
65.	Operculina turpethum (L.) Silva	Convolvuaceae	++	
66.	Oxalis latifolia H.B. & K.	Geraniaceae	++	
67.	Papaver somniferum (L.)	Papaveraceae	+	-
68.	Pelargonium graveolens (L.)	Geraniaceae	++	-
69.	Plantago ovata forsk.	Plantaginaceae	+	-
70.	Pluchea lanceolata Oliver & Hiren	Asteraceae	++	++
71.	Plumbago zeylanica (L.)	Plumbaginaceae	++	++
72.	Psoralea corylifolia (L.)	Fabaceae	++	+++
73.	Rauvolfia serpentina (L.)	Apocynaceae	++++	-
74.	Ricinus communis (L.)	Euphorbiaceae	++	++
75.	Ruta graveolens (L.)	Rutaceae	++	-
76.	Sambucus nigra (L.)	Caprifoliaceae	-	-
77.	Scoparia dulcis (L.)	Scrophulriaceae	++	++
78.	Sida cordifolia (L.)	Malvaceae	++	++
79.	Solanum incartum (L.)	Solanaceae	++++	-
80.	Soloanum indicum (L.)	Solanaceae	+++	++
81.	Spilanthes acmella Murr.	Asteraceae	++++	-
82.	Tamarix gallica Auct. Non (L.	Tamaricaceae	++	++
83.	Tribulus terrestris	Zygophyllaceae	++	-
84.	Trigoella foenum-gaecum (L.)	Fabaceae	++	++
85.	Tylophora indica (Burm. F.) Merr.	Asclepiadaceae	-	-
86.	Uraria picta (Jacq.) Desv. Ex DC.	Fabaceae	++	-
87.	Woodfordia fruticosa (L.) Kurz.	Lythraceae	++	++

Abbreviation: - = No, + = Mild, ++ = Moderate, +++ = Severe, ++++ = Very severe infection'

It is worthwhile to mention here that the plants belonging to family Solanaceae, Lamiaceae, Acanthaceae, Apiaceae and Liliaceae are more frequently infested with *Meloidogyne* species.

Here the occurrence of various phytoparasitic nematodes on different medicinal plants have been described crop wise.

Mint (*Mentha* spp.)

Among different medicinal and aromatic plants mints come in the front line not only because of its pharmaceutical importance but also due to its manifold uses for the farmers. The farmer in tropical countries can grow it as a bonus crop as it fits well in the cropping system with other crops like paddy, wheat, potato, sugarcane, maize, okra, carrot, onion, spinach, pigeon pea, cowpea etc. This crop also generates significant employment and earns a lot of foreign exchange. Different types of mints, which are commercially cultivated in tropical and subtropical countries are: Menthol mint (*Mentha arvensis*), Peppermint (*Mentha piperita),* Spearmint (*Mentha spicata*), Scotch spearmint *(Mentha cardiaca*), Bergamot mint (*Mentha citrata*) and Garden mint (*Mentha viridis*).

Nematodes of Mints

Nematodes have been identified as major pests of several mint species. The important nematodes which are affecting the yield are: *Meloidogyne* sp., *Pratylenchus* sp. and *Tylenchorhynchus* sp. Several other phytonematodes are found to be associated with different mint species (Table 3).

Meloidogyne (Root-knot Nematode)

Root-knot nematodes attack major medicinal and aromatic plants and are cosmopolitan in nature. Only two species *i.e. Meloidogyne incognita* and *M. javanica* are globally important for the menthol mint damage but the occurrence of *M. incognita* is more than *M. javanica*. Maximum R&D work in nematodes of menthol mint has been carried out with *M. incognita* (Pandey, 2003).

Symptoms of Damage

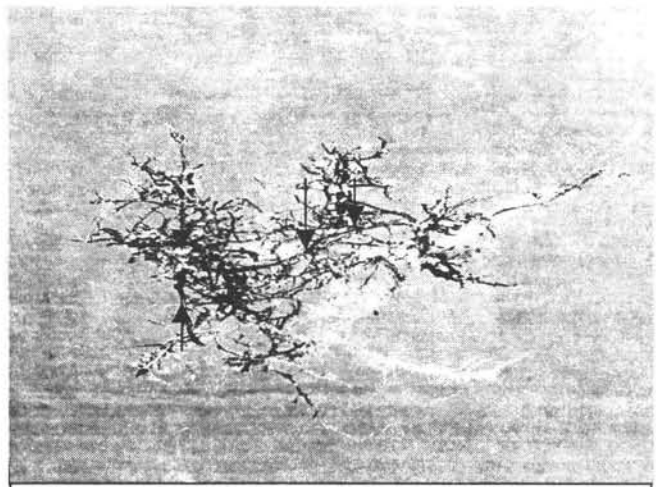
The major aerial symptoms in the fields of mint are stunting and chlorosis, which occur in patches. Root-knot infested suckers/roots bear several galls of various sizes and most of the times eggs are easily visible on the root system (Fig. 1).

Biology

The life cycle of *M. incognita* in menthol mint is completed in 28-30 days and occurs in menthol mint up to four generation under favourable condition (Pandey, 1988). The race was identified as *M. incognita* race- 2, which is predominant in Lucknow, Uttar Pradesh, India.

Survival and Disseminations

As per records the *Meloidogyne* species attack number of medicinal and aromatic plants. Since *Meloidogyne* juveniles/eggs survive in the storage root/suckers and these could be easily disseminated through suckers/roots, which are main transplanting materials. Adhered soils with suckers and alternate weed host are also main source of the root–knot nematode inoculum.



Sucker of menthol mint with enormous egg masses

Fig. 1

Environmental Factors

Meloidogyne species multiply well in sandy soil. Generally soil types where menthol mint is being cultivated is sandy loam therefore, damage caused by root-knot nematode in this region is several fold than in other regions (Pandey *et al.*, 1992). In one of the studies, Pandey *et al.* (1992) reported that the infestation of root-knot nematode was more prevalent in sandy soil than clayey, which is less suitable for nematode multiplication. As menthol mint is transplanted in January and this time period (February to April) is best suited for nematode development in menthol mint growing areas where nematode can complete three to four generations and build up their population up to the economic threshold level.

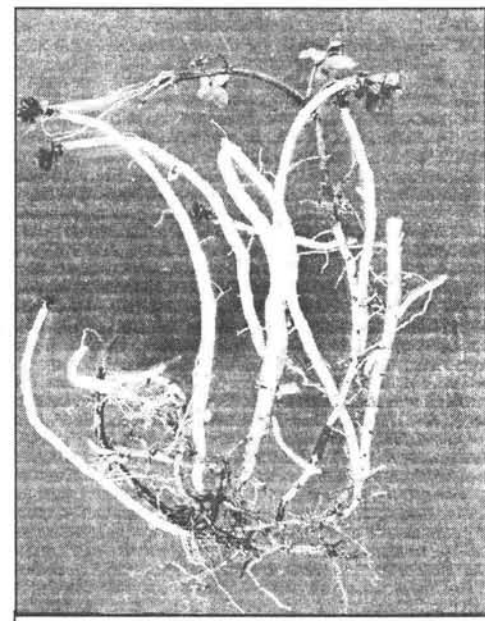
Economic Importance

Meloidogyne species reduces plant growth and oil yield up to significant level. Experiments were carried out to determine the pathogenic potentiality of different plant parasitic nematodes on menthol mint (*Mentha arvensis* L.). The pathogenic potentiality of *M. incognita* was observed on all species of *Mentha* as well as cultivars (Pandey, 1989). With an increase in load of inoculum there had been a significant decrease in oil yield, fresh and dry weight of plant and rate of photosynthesis. The reduction in different growth parameters were found to be directly correlated with inoculum load of nematode (Pandey *et al.*, 1992). Root-knot nematode (*M. incognita* & *M. javanica*) caused 25-30%

oil yield reduction in menthol mint. The quality of mint oil was also adversely affected due to nematode infection (Pandey, 1989; Pandey *et al.*, 1992).

Management of Phytonematodes in Menthol Mint

Management of phytonematodes is one of the most important prerequisite to minimise injury to crop plants. Nematode injury provide entry to a wide variety of plant-pathogenic fungi and bacteria, which may cause other serious diseases (Pandey, 2003). These microbial infections may result in greater losses than the damage from nematodes alone. Pre-plant treatment for the nematode control is essentially important because once a plant is parasitized it is really difficult to cure. The most sustainable approach to nematode control involves the integration of several strategies, including the use of pesticides, organic materials, bio-agents, resistant/ tolerant plant varieties, cultural practices etc.

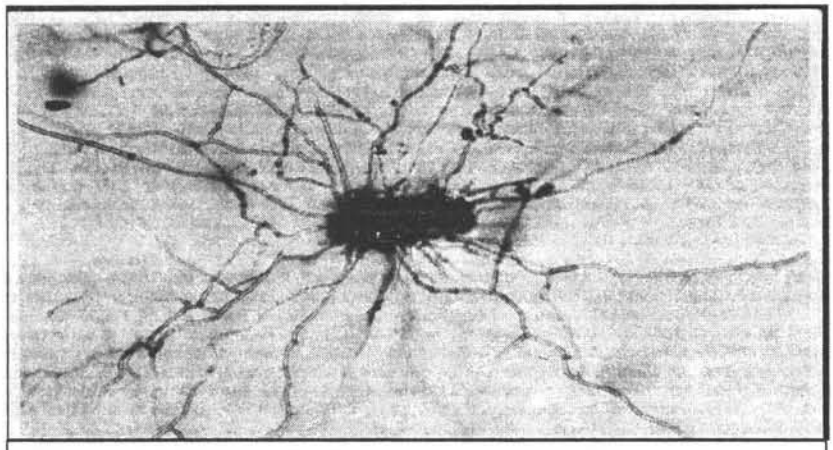


RKN infested suckers of **menthol mint**

Fig. 2

To manage root-knot nematode in menthol mint through ecofriendly way is a difficult task because of endoparasitic nature of pathogen. Studies conducted by Pandey *et al.* (1997) on interaction between *M. incognita* and VA fungi indicated that root-knot nematode, *M. incognita* multiplies well in absence of VAM fungi and significantly reduced plant growth/yield (Table 1). Root-knot nematode infection was drastically impaired when plants were inoculated with three VAM fungi simultaneously as compared to their alone inoculation. It was concluded with this experiment that VAM fungi besides improving plant growth biomass can effectively inhibit nematode infection in menthol mint.

Successful control of root-knot disease could be also achieved with the integration of carbofuran (@ 1.5kg a.i./ha) and neem cake (@ 500kg/ha) (Pandey, 2002). Significant success both in pots as well as in fields with regard to management of *M. incognita* with bio-agents, organic matter and integration of both has also been obtained (Pandey, 1995; Pandey et. *al.* 2002).



RKN egg colonised with *V. chlamydosporium*

Fig. 3

Table 3: Effect of three VAM fungi and Meloidogyne *incognita* on the productivity of *M. arvensis* (Pandey *et al.*, 1997)

Treatments	Fresh weight (g)	Dry weight (g)	% Oil yield	% Mycorrhizal infection	Root-knot indices
Untreated-uninoculated	395.2	107.1	0.51	-	-
Untreated-inoculated	285.0 (-27.8)*	77.9 (-27.2)	0.38 (-25.5)	-	3.6
Ga. – inoculated	322.0 (-18.5)	91.6 (-14.5)	0.40 (-21.5)	42.3	2.3
Gf. – Inoculated	333.0 (-15.7)	93.8 (-12.4)	0.41 (-19.6)	58.2	2.0
Gm. – Inoculated	388 (-1.8)	105.9 (-1.1)	0.48 (-5.9)	63.5	1.6
Ga.+Gf.+Gm.-Inoculated	360.0 (-8.9)	99.8 (-6.8)	0.46 (-9.8)	78.5	1.3

Abbreviations: Uninoc. = Uninoculated, Inoc. = Inoculated with *M. incognita,* Ga.= Glomus aggregatum, Gf.= *Glomus fasciculatum*, Gm.=*Glomus mosseae*, * = Percent increase (+) or decrease (-) over untreated-uninoculated control.

Large number of tactics were applied to manage phytonematode problems of menthol mint. Pandey *et al.* (1998) carried out field trials to manage root-knot nematode through use of mycorrhizal fungi (*Glomus aggregatum, G. mosseae, G. feasiculatum*), bio-agents (*Trichoderma harzianum*), oil seed cakes of mustard (*Brassica compestris*), neem oil seed cake (*Azadirachta indica*) and Carbofuran in the management of root-knot nematode (*M. incognita*) and their impact on growth/yield of menthol mint var. Kosi. The population of *M. incognita* was higher (680-1040/200g soil) in untreated plots than treated ones (200-460/200g soil). Maximum reduction in nematode population was recorded in neem cake treated soil followed by mustard cake, carbofuran and bio-agents. The root-knot nematode population showed a quadratic down-up change which decreased after the imposition of treatment and showed a substantial increase at the time of crop maturity in June. Higher plant growth was observed in the soil treated with oil seed cakes (210q/ha herbage) in comparison to untreated control (146.6 q/ha herbage). The crop produced significantly higher oil content (2.7%) and yield (151.0 kg/ha) by neem cake treatment followed by mustard cake (2.7%, 143.6 kg/ha0, *Trichoderma harzianum* (2.5%, 116.4 kg /ha), *Glomus aggregatum* (2.4%, 112.2kg / ha) and Carbofuran (2.3%, 114.2 kg/ha) respectively. The untreated crop synthesised and yielded much less oil (1.8%, 70.4 kg/ha). Similarly different organic inputs decreased root-knot infection to menthol mint var. Himalaya and substantially increased plant growth parameters and yield of the crop. In another experiment the use of Vermicompost and different distillation waste were found to enhance the growth/ yield of different mint species and reduced phytonematode population at significant level (Pandey *et al.*, Unpublished).

Resistant Varieties

Several germplasm available with CIMAP, Lucknow gene bank were screened for their resistance to *Meloidogyne incognita* (Pandey and Patra, 2001). Most of the 25 accessions screened for *M. incognita* infection, showed susceptible reaction to nematode infection of varying degree. Highest root-knot infection was rated on Siwalik, SS-18 and Himalaya. Comparatively moderate reaction was found on SS-11, SS-27, Gomti, Kosi, *M. cardiaca* and MAH-1respectively. The lowest infection level was found on SS-5, SS-5-4, Kalka and SS-20. On the other hand moderate to high degree of resistance was noticed on SS-1-4, SS-2-7, SS-15, SS-26, SS-36, *Mentha piperita* cv. Kukrail, *M. spicata* cv. Neera, M. *spicata* cv. Arka, *M. citrata* cv. Kiran, *M. gracilis* and *M. viridis* respectively. These can be further exploited for future breeding programme for developing root-knot resistant mint genotypes.

Experiments conducted in our experimental farm suggest that inclusion of some non-host like mustard and wheat crop help to a great extent in reducing the population of *Meloidogyne* spp. and its occurrence and severity on menthol mint crop (Table-3). The late transplanted mint technology developed at Central Institute of Medicinal and Aromatic Plants, Lucknow which allows farmers to have non-host crop like wheat, mustard etc. has greatly benefited the farmer in fighting root-knot nematode menace to some extent. Further the higher temperature prevailing during the transplanted cropping season (April-July) also checks the nematode population buildup and infection of menthol mint crop.

Henbanes

Henbanes (Hyoscyamus *muticus*, *H. niger* & *H. albus*) are one of the chief source of tropane alkaloid *viz.* hyoscine, hyoscyamine and atropine. The hyoscine and its derivatives have been used in pharmaceutical preparations, since they are having anticholinergic, antiphasmodic and mydriatic properties (Pandey, 1998).

Nematodes of Henbane

Many phytonematodes have been reported to be associated with different species of henbane but the only one nematode have been reported to cause serious damage to the crop is root-knot nematode (*Meloidogyne* spp.).

Root-knot Nematodes of Henbane

These different species of henbane are heavily infested with root-knot nematode, *M. incognita* & *M. javanica*, which cause significant damage to the crop (Pandey, 1990).

Symptoms of Damage

In the field *Hyoscyamus muticus*, *H. niger* & *H. albus* were chlorotic and stunted showing a patchy appearance with fewer smaller leaves and flowers. The roots of infested plants were severely galled to various degree. Experiments carried out in CIMAP indicated that even 3-4 larvae/g soil cause significant damage to the crop (Haseeb and Pandey, 1989; Pandey, 1990).

Control Measures

Some ecofriendly approaches also been made to manage this important pest on these plants (Pandey, 1997a). In one of the experiment, Pandey *et al.* (1999) observed that the plants with inoculum of different mycorrhizal fungi showed better growth in comparison to untreated - *M. incognita* inoculated and untreated-uninoculated one. The best results were obtained with *G. aggregatum* for increasing growth/biomass of plants and reduction in root-knot nematode population.

Healthy & root-knot infested plant and roots of *H.muticus*

Fig. 4

For example in Hyoscyamus niger the nematode population was observed maximum in nematode alone inoculated plants than plants inoculated in combination of nematode and bio-inoculants resulting significant reduction of *M. incognita* (Mi) population especially in combined treatment followed by *Pseudomonas florescens* (Pf) or *Glomus aggregatum* (Ga) inoculated treatments. Thus, the degree of losses in biomass production caused by Mi in combination with the bio inoculants were significantly reduced over the losses observed with Mi alone. Among the four combined inoculations, a combination of all the four with Mi appeared to be the best followed by Ga or Pf which is observed statistically insignificant. Root colonisation and spore population of VAM-fungi was observed 16 weeks after inoculation. Maximum spore population and percent root colonisation was observed in combined treatment, which was followed by Ga, Gm

and Gf. It is worth mentioning here that root colonisation was found directly proportional to spore population and biomass yield from the crop (Table-1).

Experimental findings indicated that application of bio-inoculants have not only enhanced the total biomass yield of *H. niger* but it had also significantly decreased the multiplication of nematode, however, a significantly higher reduction was recorded in the treatment where all bio-inoculants are combined (Table-2). This may be attributed with the fact that these bio-agents are secreting potent chemicals which are either non-favourable for multiplication of Mi or inducing tolerance in the plant against the attack of root knot nematodes. Nematode reproduction was higher in plants inoculated with nematode alone than in plants with combined inoculation of nematodes with bio-inoculants (Table-2).

Thus, experimental evidences indicated that mixed inoculation of rhizobacterium with VAM fungi could be considered as biological management instead of nematicides for reducing the deleterious effect of root knot disease in black henbane.

Table 4: Effect of bio-inoculants and *M. incognita* on the productivity, percent root infection and spore population on *H. niger

Treatments	Fresh biomass weight(g)			Percent root colonisation	VAM spore population/ 100g soil
	Root	Shoot	Total		
C	30.6	179.4	210.00	-	-
MI	18.4	102.2	120.60 (-42.57)	-	-
PF	35.5	193.3	228.80 (+8.95)	-	-
PF+ MI	32.8	138.2	171.00 (-19.00)	-	-
GA	34.6	198.4	233.00 (+10.95)	78	1020
GA+ MI	32.2	140.5	172.70 (-17.76)	65	780
GF	31.8	180.2	212.00 (+0.95)	47	680
GF + MI	24.3	120.3	144.60 (-31.14)	38	490
GM	30.4	180.5	210.90 (+0.43)	59	770
GM + MI	22.8	119.2	142.00 (-32.38)	45	580
PF+GA+GF+GM	37.20	216.50	253.70 (+20.80)	82	1060
PF+GA+GF+GM+MI	33.60	168.40	202.00 (-3.81)	68	800
CD at 5% level	3.28	10.76	12.01	12.05	49.26
at 1% level	4.76	16.24	16.08	17.27	66.51

*= Each value is an average of five replications.

(.) = Figure in Parenthesis denotes percent increase (+) or decrease (-) over uninoculated control.

Abbreviations: C = Uninoculated control, MI = *Meloidogyne incognita*, PF = *Pseudomonas fluorescens*, GA = *Glomus aggregatum*, GF = *Glomus fasciculatum*, GM = *Glomus mosseae.*

Table 5: Effect of bio-inoculants on population dynamics of *M. incognita* on *H. niger**

Treatments	Nematode population			Reproduction factor (Rf)	Root-knot Index
	Root	l Soil	Total nematode population (Root + Soil)		
C	-	-	-	-	-
MI	16080	24620	40700	8.14	4.0
PF	-	-	-	-	-
PF + MI	10020	11180	21200 (-47.90)	4.24	1.33
GA	-	-	-	-	-
GA+ MI	10940	11660	22600 (-44.47)	4.52	1.66
GF	-	-	-	-	-
GF+ MI	12880	16020	28900 (-28.99)	5.78	2.66
GM	-	-	-	-	-
GM + MI	12060	18240	30260 (-25.65)	6.05	3.00
PF+GA+GF+GM	-	-	-	-	-
PF+GA+GF+GM+MI	10000	10140	20140 (-50.51)	4.028	1.00
CD at 5% level	1280.63	1842.69	2426.14	-	1.16
at 1% level	1865.06	2686.57	3571.89	-	2.04

* = Each value is an average of five replications.

(.) = Parenthesis indicates the percent decrease (-) in nematode population over Mi inoculated control.

Abbreviations: C = Uninoculated control, MI = *Meloidogyne incognita*, PF = *Pseudomonas fluorescens*, GA = *Glomus aggregatum*, GF = *Glomus fasciculatum*, GM = *Glomus mosseae.*

Similar results were also obtained with different bio-agents in *H. muticus* plants (Pandey *et al.*, 2000). Few essential oils were also used in another experiment to manage root-knot nematode population in *H. niger* (Pandey *et al.*, 2000a). It was observed that oils of *Cymbopogon martinii, C. wintrianus, Ocimum basilicum* and *Mentha arvensis* were quite effective in reducing M. incognita population and improving the growth of plant; the oil of *C. martinii* (@2ml/pot) being most effective (Table 3).

Davana

Root-knot Nematode

Davana (*Artemisia pallens* Wall) is an important aromatic plant in USA, Europe, Japan and India. The davana oil used extensively in food, flavour, perfumery industries throughout world. The major constituents of oilcinnamyl, cinnamate, fenchyl alcohol, codinene, 10-14 phenolor acids, sesquiterpene, linalool, eugenol and geraniol. In India it is cultivated in the states of Andhra Pradesh, Tamil Nadu, and Kerala. India is major exporter of davana oil to France and USA. Root-knot nematode (Meloidogyne *incognita* and *M. javanica*) become one of the major constraint for the successful cultivation of davana.

The root knot infected plant shows a gradual decline characterised by stunted plant growth, yellowing of the leaves, fewer buds and tillers. In nursey stage the plant was severely attached by *M. incognita*, resulting great loss of planting materials. The economic threshold level for the crop was found 1 larvae of *M. incognita*/ 2g soil. Sandy spoil and continuous availability of soil moisture proved to be very congenial for the rapid multiplication and development of nematodes.

Several experiments were conducted for the management of root-knot nematode on davana but neem cake found better than any chemical for decreasing nematode infestation in davan (Pandey, 1994).

References

Bergeson, G. B. and Green, Jr. R. J. (1979). Damage to cultivars of peppermint, *Mentha piperita* by the lesion nematode *Pratylenchus penetrans* in Indiana. *J. Nematol.* 7: 654.

Emenjaud, D., Minot, J. C., Voisin, R. and Guiran G. de. 1990. *Pratylenchoides laticauda* on peppermint in Southern Alps, host range, population densities in different crop relations and host suitability of three mint subspecies. *Meded Van de Facult Land Rijksun Gent* **55** (2b): 779-786.

Faulkner, L.R. (1962). Pathogenicity and population dynamics of Pratylenchus hamatus Thorne and Allen on Mentha species. *Phytopathology* **52** (8): 731.

Gokte, N. and Mathur, V.K. (1990). Thermal therapy for the eradication of Mentha spicata roots infected with Meloidogyne incognita. *FAO Plant Protect. Bull.* **8** (4): 213-215.

Haseeb, A. and Pandey, R. (1989). Root-knot disease of henbane, *Hyoscyamus*- A new disease records. *Tropical Pest Management* **35**: 212-21.

Haseeb, A. and Pandey, R. (1990). Root-knot nematodes- a constraint to cultivation of Davana, *Artemisia pallens*. *Tropical Pest Management* **36**: 317-319.

Horner, C. E. and Jensen, J. J. (1954). Nematode associated with mints in Oregon. *Plant Disease Reporter* **38** (1): 39-41.

Ingham, R. E.; Newcomb, G. B. and Morris, M. A. (1988). Spring nematicide application for control of root lesion and pin nematodes of peppermint, 1987. *Fungicide and Nematicide Test* **43**: 170p.

Inserra, R. N. and Rhode, R. A. (1989). Some nematode problems of spearmint in Florida. *Nematology Circular (Gainesville, U.S.A.)* No. **167**: 3p.

Meyer, S. L. F and Roberts, D.P. (2002). Combination of biocontrol agents for management of plant parasitic nematodes and soil borne plant pathogenic fungi. *J. Nematology* **34** (1): 1-8.

McSorley, R. (1998). Alternative practices for managing plant parasitic nematodes. *American Journal of Alternative Agriculture* **13** (3): 98-104.

Pandey, R. and N.K. Patra (2001). Screening mint (*Mentha* spp.) accessions against root-knot nematode infection. *Journal of Spices and Aromatic Crops* **10** (1): 55-56.

Pandey, R. (1990). Pathogenicity and reproduction of *Meloidogyne incognita* on *Hyoscyamus albus* and rhizospheric association of other phytoparasitic nematodes. *International Nematology Network Newsletter* 7 (4): 34-37.

Pandey, R. (1993). Conceptual models for the management of root-knot and lesion nematodes in important medicinal and aromatic plants. *Afro-Asian Journal of Nematology* **3** (1): 103-106.

Pandey, R. (1994). Comparative performance of oil seed cakes and pesticides in the management of root-knot disease of Davana. *Nematologia Mediterranea* **22**: 17-19.

Pandey, R. (1995). Application of oil seed cake, pesticides and dry leaf matter on the reproduction potential of *Meloidogyne incognita* and yield of Japanese mint. *Ind. J. Nematol.* **25** (1): 12-13.

Pandey, R. (1997a). Ecofriendly approaches for the management of root-knot nematode on black henbane. *Indian J. Nematol.* **27** (2): 175-178.

Pandey. (1997b). Seasonal variation in population of phytonematodes associated with peppermint (*Mentha piperita* L.) and spearmint (*Mentha spicata* L.). *Journal of Aromatic & Spices Crops* **6** (2): 149-151.

Pandey, R. (1997c). Comparative potentiality of *Pratylenchus thornei* on different mint species. *Indian J. Plant Pathol.* **15** (1&2): 24-30

Pandey, R. (1998a). "Nematode Pests of Medicinal and Aromatic Plants and their management" in *Phytonematology- Aspects and Prospects* (Edited By Dr. P.C. Trivedi, Reader Department of Botany, University of Rajasthan, Jaipur): 177-216.

Pandey, R. (1998b). Phytopathological impact of root-knot nematode on some medicinal and aromatic plants. *Journal of Medicinal and Aromatic Crop Sciences* **20**: 67-84.

Pandey, R. (1999a). Management of phytonematodes through fungal antagonists. *Journal of Medicinal and Aromatic Plant Sciences*: **21** (In Press)

Pandey, R. (1999b). Spatial and temporal dynamics of phytonematodes in arable soil planted with Japanese mint. *Journal of Mycology and Plant Pathol.* **29** (2): 232-235.

Pandey, R. (2000). Additive effect of three organic materials and pesticides on the reproduction of *Meloidogyne incognita* and yield of *Mentha arvensis*. *Nematropica* **30**: 155-160.

Pandey, R. (2003). "Mint Nematology- Current Status and Future Needs" in *Advances in Nematology* (Eds. P.C. Trivedi Professor, Department of Botany, University of Rajasthan, Jaipur): 155-166.

Pandey, R. and Kalra, A. (2002): Root-knot disease of Aswagandha and their ecofriendly and cost effective management. *Journal of Mycology and Plant Pathology* (In Press).

Pandey, R., Haseeb, A. and Husain, A. (1992). Distribution, Pathogenicity and Management of *Meloidogyne incognita* on *Mentha arvensis* cv. MAS-1. *Afro-Asian Journal of Nematology* **2** (1): 27-34.

Pandey, R, Singh, H. B. and Gupta, M. L. (1997). Antagonistic impact of Vesicular-arbuscular (VAM) on *Meloidogyne incognita* population development in Japanese mint. *Int. J. Tropical Plant Disease* **15**: 237-245.

Pandey, R., Singh, H. N., Gupta, M. L., Shukla, R. S. and Kumar, S. (1998). Infection potential of stunt nematode on palmarosa. *Indian J. Plant Pathol* **16**: 68-69.

Pandey, R., Gupta, M. L., Singh, H. B. and Kumar, S. (1999). Interaction potentialities of Vesicular-arbuscular mycorrhizal fungi with root knot nematode, *Meloidogyne incognita* on black henbane. *Bio resource Technol.* **69**: 275-278.

Pandey, R., A. Kalra and S. Kumar (2000a). Efficacy of various essential oils in the management of root-knot disease in black henbane. In Proc. of Centennial Conf. "On Spices and Aromatic plants," 20-23 September 2000, at IISR, Calicut: 263-266.

Pandey, R., Singh, H.B. and Kalra, A. (2000b.) Microbial management of plant parasitic nematodes. *Int. J. Tropical Plant Disease* **18**: 1-23.

Pandey, R., Gupta, M. L., Singh, H.B., Singh, H.N. and S.Kumar (2000c). Disease management potentiality of VAM fungi to *Meloidogyne incognita* on *Hyoscyamus muticus* In Proc. of

International conference on " Integrated plant disease management for sustainable agriculture", IARI, New Delhi pp. 1239-1240.

Pandey, R., Singh, H.B., Gupta, M.L., Singh, H.N., Sharma, S. and S. Kumar (1998). Efficacy of VAM fungi, green manure, organic materials and pesticides in the management of root-knot nematode in menthol mint. Proceedings of national Symposium "On rational approaches in nematode management for sustainable agriculture" at GAU, Anand (Eds. S.C. Dhawan & K.K. Kaushal): 47-50.

Pandey, R., Kalra, A., Gupta, M. L. and Singh S.C. (2003). *Bacopa monnieri* damaged by root-knot nematode and remedial measures. *Journal of Tropical Medicinal Plants* (In Press).

Pinkerton, J. N. (1984). Relationship of *Pratylenchus penetrans* (Cobb, 1917) population density and yield of peppermint, *Mentha piperita* L. Dissertation Abstract *Int. B. (Science & Engineering)* **44** (12): 3593b.

Rhode, H. L. (1984). Control of *Pratylenchus scribeneri* on spearmint, *Mentha spicata* with nonfumigant nematicides. *Nematropica* **14** (1): 85-89.

Sikora, R.A. 1992. Management of the antagonistic potential in agricultural ecosystem for the biological control of plant parasitic nematodes. *Ann. Rev. Phytopathol.* **30**: 245-270.

Skotland, C.B. and Menzies, J. P. (1957). Two peppermint diseases found in Yakima valley of Washington. *Plant Disease Report.* **41**: 494.

❑❑❑

5

Nematode Management through Cropping Systems–A Conceptual Analysis

R. S. Kanwar and R. K. Walia

Introduction

The history of cropping system for the control of plant parasitic nematodes dates back to 1870s when Kuhn and his associates recommended growing of non-host crops for the control of sugarbeet cyst nematode, *Heterodera schachtii* (cf. Thorne, 1961) in Germany. Cropping system is more effective for the management of host-specific nematodes like *Heterodera* and *Globodera* spp. Polyphagous nematodes such as *Meloidogyne* and *Pratylenchus* spp. can also be managed through cropping system by careful planning and selection of crops. Generally, cropping system as a nematode management practice is considered useful for low value crops in subsistence agriculture. In the changing scenario of world agriculture and to compete in the global market, there is a need to cut down the cost of cultivation without reducing productivity. Under such conditions, cropping systems can play a significant role in pest management, in high value crops as well.

Cropping System Concept

Cropping system is defined variously by different workers. Trivedi & Barker (1986) consider crop rotation and cropping system as similar concepts, while Okigbo (1978) considered crop rotation as a part of cropping system. He defined **cropping system** as *the cropping pattern utilised on a given farm in addition to the management of resources based on available technology all of which determine the nature or make up of the system* and **cropping pattern** as *the yearly sequence and spatial arrangement of crops, or the alternation of crops including fallow on the given area.* Thus, cropping system covers all kinds of crop sequences including continuous monoculture and crop rotation. Wilson (1982) defined cropping system as *an ecosystem in which man uses plants to direct the flow of energy for his own benefit i.e., for food, fibre, fuel and shelter.*

In the views of Nusbaum & Ferris (1973), cropping system covers all kinds of crop sequences including monoculture, whereas crop rotation implies an inflexible cycle or a fixed series of crops. Raymundo (1985) defined cropping system as the *growing of crops along with required technology for their production.* According to Somani & Tikka (1984) **crop rotation** is *a definite succession of crops following one another in a specific order*, and **cropping system** is *pattern of crops taken up for a given piece of land, or order in which crops are cultivated on a piece of land for a fixed period, associated with soil management practices such as tillage, manuring and irrigation.*

Types of Cropping System

Beets (1978) categorised cropping systems in two broad groups; monocropping systems—in which a single genotype or species is planted at the same time in intimate or loose association, and multiple cropping system—in which more than one genotypes or species are planted in one calendar year. Raymundo (1985) classified cropping system on the basis of arrangement of crops in time and space. He includes crop rotation, fallow rotation, relay cropping and discontinuous planting under temporal cropping system which indicates distribution of crops over a period of time. Mixed cropping, intercropping and strip cropping, representing arrangement of crop species in a piece of land, come under spatial cropping system.

Cropping System in Relation to Nematode Population

Nematode populations are greatly affected by the crops and cropping systems. Monoculture of a susceptible host or cultivation of different susceptible crops in succession enhances nematode populations, whereas use of resistant or poor host crops helps in reducing the nematode populations (Mai & Lownsbery, 1952; Khan *et al.*, 1975; Castillo *et al.*, 1977; Kanwar & Bhatti, 1992 b). The degree of success achieved in nematode population reduction, however, depends upon the cropping system, level of resistance and susceptibility in crop (Trivedi & Barker, 1986), pathogen associated, nature and length of rotation, and weed hosts (Clayton *et al.*, 1944).

Knowledge of the nematode behaviour (host range, mode of survival, period of activity etc.) and the nature of crop(s) (host status, duration, growing season and growth requirements) are essential in designing a cropping system for nematode control. A cropping system should be selected with a special consideration of host status so that the previous crop does not produce a population larger than the economic threshold level of the succeeding crop in the system. In nematology, host status of a crop is determined by the performance of parasite (reproduction). Efficient or good hosts are the plants on

which high nematode densities can build up (Jones, 1956). However, nematode populations tend to reach a ceiling level which is regarded as a measure of host status of a plant. Ceiling level is high in case of good hosts and low for poor hosts.

Seinhorst (1967) explained that maximum rate of reproduction (a) and equilibrium density (E) together define the host status of a plant for a given set of conditions. For a nematode species, both these factors may vary from plant to plant, independently of each other. On good host, both 'a' and 'E' are large, and on poor host both are small. On intermediate hosts, either of the two may be large and the other small or both intermediate. On a non-host, no reproduction occurs and E = 0. For including a crop/plant species in cropping system host should be considered from two angles, *i.e.*, relative suitability for parasite- nematode reproduction in this case, and relative vulnerability to damage.

A host may be classified as tolerant, resistant, susceptible and intolerant (Dropkin and Nelson, 1960; Rohde, 1972; Cook, 1974) on the basis of performance of both the host and parasite. Susceptible and intolerant hosts are agriculturally unsuitable for inclusion in cropping system. Tolerant and resistant hosts may be desirable in cropping system although they too have limitations (Kanwar & Bhatti, 1994). Oteifa & Elgindi (1961) devised a model for determining tolerance levels in nematode-infected plants. Resistance and tolerance are independent plant characters and both resistant and susceptible plants may be tolerant or intolerant (Fox & Spasoff, 1976; Fisher *et al.*, 1981). Resistant-tolerant crop variety is the best option in the cropping system.

Spatial Cropping System

The aim of this type of cropping system is to reduce the feeding sites which in turn affect the nematode population build up. In spatial cropping system, generally diverse crops are grown in the same field in loose or close association. The crops included with susceptible crops may be poor hosts, non-hosts or antagonistic crops. Nematode populations are affected by antagonistic action (*e.g., Tagetes* and *Crotalaria*) or starvation effect. Apart from reducing nematode populations, it has some other advantages also such as:

- ensures against total crop failure in highly unstable environment,
- maximises the return on the farmer's small unmechanised holdings,
- various crops are harvested at different times ensuring the survival of farm family,
- soil fertility is utilised properly by different crops, and

- reduces the risk of development of new biotypes by providing chances to the parasite for feeding and development on susceptible hosts.

Temporal Cropping System

Amongst different types of cropping systems, most of the work pertains to crop rotation. History of crop rotation is as long as the history of agriculture. But in earlier times it was used to tide over 'soil exhaustion'. In modern agriculture, this practice is used for controlling weeds, pests and diseases. Of the various types of temporal cropping systems, crop rotation is most widely used for nematode control world-over. Basic principles of this practice for the management of nematode populations as given by Nusbaum & Ferris (1973) are:

- reduction of initial nematode densities, and establishment and completion of early growth of subsequent crop before being heavily attacked, and
- preservation of competitive, antagonistic and predacious nematodes and other organisms at population densities effective in buffering the pathogenic species.

Crop rotation has been recommended for the control of plant parasitic nematodes since long (Kuhn *et al.*, 1874 cf Thorne, 1961; Bessey, 1911; Ayyar, 1933; Godfrey, 1923; Steiner, 1930) and the voluminous literature accumulated on this aspect has been reviewed by several workers (Amosu, 1982; Davide & Castillo, 1981, Raymundo, 1985; Nusbaum & Ferris, 1973; Trivedi & Barker, 1986).

Cropping System in Integrated Nematode Management

Cropping system is compatible with almost all the available management practices. It is an indispensible component of integrated pest management. Crop rotation has been used effectively in integrated management of plant parasitic nematodes (Birat, 1966; Johnson, 1985; Van Gundy *et al.*, 1974), however most of the work is confined to its integration with chemicals (Cooper 1952; Johnson *et al.*, 1976; Koen 1966; Johnson & Campbell 1977, 1980, Chen *et al.*, 1990). Crop rotation in combination with other non-chemical methods also has proved successful for nematode management in many instances. In Mexico, problem of wheat caused by *Pratylenchus thornei* with other soil factors (brown mite, fungi, bacteria and lack of proper fertilizers) was solved practically by combining crop rotation with selection of variety, planting in cool soil (15°C) and application of nitrogenous fertilizers (Van Gundy *et al.*,1974). Bird (1981) has described cases of management of *H. schachtii* in sugarbeet and *Meloidogyne* spp. in tomato, with combination of crop rotation and other methods. Nematicides are available but rarely

required in the integrated system adopted for the management of these nematodes. Van Gundy (1972) thus rightly pointed out that "crop rotation is one of the options in regulating nematode populations, but its greatest potential undoubtedly lies in the role it may play in integrated control programmes of the future."

Cropping System Analysis

Nematode populations are largely governed by crops and cropping systems (Oostenbrink, 1961). Damage caused to crops by plant parasitic nematodes is density dependent, and sequential alternation of crops with varying degrees of susceptibility can produce striking results in reducing crop losses (Noe, 1986). Several models developed by different workers to correlate nematode density with crop damage have been discussed by Ferris (1981). But a crop and cropping system effective in reducing nematode population may not necessarily be economical. For example, a rotation: carrot-onion-okra-tomato maintained low population of *M. javanica* but was not as economical as tomato-garlic-ridgegourd-tomato or monoculture of tomato (Kanwar, 1989). A cropping system good for nematologist may not be good for an agronomist or economist. Hence, for the success of a cropping system, besides nematode population, crop yield and economics (monetary value in terms of prevailing prices) must also be considered. Although, prices of crops vary from place to place and also at different times, nevertheless the chances of success of location-specific cropping system developed with multi-disciplinary approach would be more.

Factors to be Considered in Developing Cropping Systems

Success of cropping system in nematode management lies in the selection of suitable crops which can be included in it for reducing the nematode populations. Understanding interaction of other micro-organisms with nematode and resulting effect on host crops can help increase the efficiency of the system. Besides, the following factors should be kept in mind while developing a cropping system:

Crop Utility

The crops to be included should be useful and of economic value to the user of the cropping system. In India, marigold though effective in reducing nematode population is not economical in rural areas. However, it can be useful near cities where market for flowers is available. Likewise, this crop has no economic value in Philippines and hence a cropping system with marigold may not be accepted by farmers (Davide & Castillo, 1981). Contrarily, in Peru this crop can be readily accepted by farmers because

anthocyanin extracted from marigold is used in poultry feeds. Cereals are very effective in reducing populations of *Meloidogyne javanica* and *M. incognita* in vegetable crops but vegetable growers generally do not agree to include cereals due to their low value. Cluster bean (*Cyamopsis tetragonoloba*) is a multipurpose crop in India (used for vegetable, fodder and industrial purpose) and is very effective in managing root-knot nematode (Kanwar & Bhatti, 1998). Thus, it can be recommended and easily accepted by growers for suppressing root-knot nematode populations.

Feasibility to Local Conditions

A cropping system should be developed keeping in view the feasibility of the system. For example, cropping system including fallowing, though effective in nematode control may not be practically feasible for the farmers having small land holdings. Similarly, crops like cluster bean and fodder maize are very promising in suppressing the population of *M. javanica* and can be included in rotations (Kanwar, 1989) but these crops can be accepted by farmers only if they keep livestock on their farm or marketing is available for such fodder crops.

The adaptability of the selected exotic crop to prevailing agro-climatic conditions should be seriously considered prior to its inclusion in the system; however, preference should be made from among the locally grown crops.

Availability of Resources

Availability of resources to meet the requirement of crops in cropping system is an important factor to be considered. A rice-based cropping system, for instance, will be useless for an area where rainfall and irrigation facilities are inadequate to fulfil the requirement of rice crop. Therefore, the necessary facilities for cultivation of a crop to be recommended must exist.

Consideration of Other Pests

There are many instances in which growing of a crop for management of a nematode species increased the populations of other parasitic nematodes. Similarly, if crops raised for reducing the populations of a target nematode are severely damaged by other insect pests or diseases then use of such crops becomes meaningless. Therefore, the crops in cropping system should not foster other major pest problems. A crop with multiple pest resistance will be more suitable under such conditions.

Limitations of Cropping System in Nematode Management

Cropping system is very effective and widely used practice for nematode management in annual crops. Like other methods, it also has certain limitations, which are as follows:

Unavailability of Suitable Crops

Success of cropping system in nematode control depends upon the availability of non-host/poor host crops. In many cases such crops are not available due to agronomic, economic or climatic reasons.

Development of New Biotypes

There are evidences that when a poor host crop or resistant variety is grown continuously in rotation with susceptible host, the development of new biotypes takes place which can attack resistant/non-host crop also (Sasser & Nusbaum 1955; Riggs & Winstead, 1959; Nubaum & Barker, 1971). Hence, after sometime the cropping system becomes ineffective.

Increase in Population of Other Plant Parasitic Nematodes

Nematode communities are polyspecific (Ooestenbrink, 1966) and have overlapping host range. When we attempt to suppress target nematode pest by withdrawing its favourable host and growing some non-host crop, populations of other nematodes may increase to high level to which new crop is a favourable host. When maize was introduced in rotation for the control of *M. javanica* in vegetable crops the population of *Hoplolaimus indicus* and *Tylenchorhynchus goffarti* increased to high levels (ca. 4 and 5 nematodes per g of soil, respectively) in single crop season (Kanwar & Bhatti, 1993). Thus, had this crop been grown for several seasons perhaps these nematodes would have attained the status of the major pests.

Population Resurgence

Multivoltine nature, high fecundity and ability to survive under adverse conditions (overwintering, anhydrobiosis etc.) enable plant parasitic nematodes to multiply rapidly when conditions become favourable. When a susceptible host is grown after poor host, populations resurge quickly (Rodriguez-Kabana & Touchton, 1984; Kanwar & Bhatti, 1992a) so that only one or two susceptible crops can be taken.

Problem of Weeds

Each species of plant parasitic nematodes attacks several plants including weeds. Role of weeds in perpetuation of pests and diseases is well established. Vats & Bajaj (1998) have discussed the role of weeds in ecology and management of nematode pests of crops. Weeds may act as collateral and alternate host of nematodes rendering the cropping system ineffective for nematode management.

Not Effective in Perennials

Cropping system is practicable only in annual crops. However, intercropping of antagonistic crops like *Tagetes, Crotalaria, Asparagus* etc. can be used to reduce nematode populations in perennial crops (Baghel & Gupta, 1986).

Farmers' Resistance to Change Crop

Due to fast resurgence and persistent nature of nematodes the susceptible crops are recommended to be grown in long rotations (very less frequency). Farmers may not appreciate the crops recommended in a cropping system due to their choice for a particular crop as reported by Smit & Bos (1976) in northern Nigeria where farmers like to grow continuous tomato in spite of low yields. Similar situation prevails in Haryana with the farmers facing problem of cereal cyst nematode in wheat. Under such conditions where growers do not want to abandon monocropping, rotation of variety may be the alternative.

Conclusions

The biology of target nematode, its races/pathotypes, host range and survival in absence of host should be well understood before attempting to manage plant nematodes through cropping system. Some polyphagous nematode species may feed and multiply on weeds making the cropping system ineffective. Therefore, care must be taken to keep the non-host/resistant crop free from weeds. Most of species of root-knot nematode are less persistent in soil and their populations decline rapidly in the absence of susceptible crops. Thus by growing non-host crops for one or two seasons, their population can be brought below ETL of the desired susceptible crop. Host specificity of nematodes like *Globodera* and *Heterodera* provides opportunity in selection of non-host crops. However, due to their longer persistence, suspension of susceptible crop cultivation for 2-3 years becomes obligatory for the success of cropping system.

Situations become more complicated when two or more major nematode pests are present together in the same field. Occurrence of *H. avenae* and *M. incognita* is common in many fields in Mahendergarh district (Haryana). Likewise, concomitant occurrence of *M. javanica* and *M. incognita* with *Rotylenchulus reniformis* is not uncommon in many vegetable fields. One has to be more careful in selecting a cropping system for such a situation. Some farmers would not like to abandon monoculture, for them 'gene rotation' (rotation with resistant variety) can be useful. However, cultivation of resistant variety for a long period should be discouraged to avoid development of new

resistance-breaking biotypes. The cropping system should be replenished with other suitable crops after some time to mitigate the development of new biotypes, other nematode and pest problems. Cropping system can be successfully used for the management of nematodes in modern agriculture by considering these points and integration with other control practices.

References

Amosu, J.O. 1982. Control of root knot nematode by cultural practices. In: *Proc. Third IMP Res. Plan. Conf. on Root-knot Nematodes, Meloidogyne* spp., Regions IV and V, IITA, Ibadan, Nigeria, pp. 259-264.

Ayyar, P.N.K. 1933. Some experiments on the control of root gall nematode in South India *Madras agric. J.* **21**: 97-107.

Baghel, P.P.S. and Gupta, D.C. 1986. Effect of intercropping on root-knot nematode (*Meloidogyne javanica*) infesting grapevine (Var. Perlette) *Indian J. Nematol.* 16: 283-284.

Beets, W.C. 1978. Multiple cropping system reviewed. *SPAN* **21** (3): 114-116.

Bessey, E.A. 1911. *Root-knot and its control.* USDA Bur. Plant Ind. Bull. No. **217**, 89 pp.

Birat, R.B.S. 1966. Influence of cultural practices on the population of *Meloidogyne javanica* (Treub. 1885) Chitwood,1949. *Indian Phytopath.* **19**: 233-235.

Bird, G.W. 1981. "Integrate nematode management for plant protection." In: *Plant Parasitic Nematodes.* Vol. III. (B.M. Zuckerman & R.A Rhode, eds.), Academic Press, New York, pp. 355-375.

Brown, E.B. 1982. "Cultural and biological control methods." In: *Plant Nematology* (J.F.Southey, ed.,), HMSO London, pp. 269-282.

Castillo, M.B., Alejar, M.S. and Litsinger, J.A. 1977. Nematode cropping patterns-III. Composition and populations of plant parasitic nematodes in selected cropping patterns in Batangas. *Phil. Agr.* **60**: 285-292.

Chen, C., Chen, P. and Yao, G. 1990. Integrated control of nematodes (*Meloidogyne* spp.) on tobacco in Sichuan, China. *Int. Nematol. Network Newsl.* 7 (3): 45.

Clayton, E.E., Shaw, K.J., Smit, T.E., Gaines, J.G. and Graham, T.W. 1944. Tobacco disease control by crop rotation. *Phytopathology* **34**: 870-883.

Cook, R. 1974. Nature and inheritance of nematode resistance in cereals. *J. Nematol.* **6** (4): 165-174.

Cooper, W.E. 1952. Control of peanut root-knot by soil fumigation and crop rotation. *Phytopathology* **42**: 282-283.

Davide, R.G. and Castillo, M.B. 1981. "Cropping systems for the control of root-knot nematodes." In: *Proc. Third IMP Res. Plan. Conf. on Root-knot Nematodes, Meloidogyne* spp., Region VI. Jakarta, Indonesia, pp. 214-227.

Dropkin, V.H. and Nelson, P.E. 1960. The histopathology of root knot nematode infections in soybeans. *Phytopathology* **50**: 442-447.

Egunjobi, O.A. 1985. Cropping system and pest control: The nematode story. *Int. Nematol. Network Newsl.* **2** (3): 28-40.

Ferris, H. 1981. "Mathematical approaches to the assessment of crop damage." In: *Plant Parasitic Nematodes.* Vol. III (B.M. Zuckerman and R.A. Rohde, eds.), Acad. Press., New York, London, pp. 405-415.

Fisher, J.M., Rathjen and Dube, A.J. 1981. Tolerance of commercial cultivars and breeder's lines of wheat to *Heterodera avenae. Aust. J. Agric. Res.* **32**: 545-551.

Fox, J.A. and Spasoff, L. 1976. Resistance and tolerance of tobacco to *Heterodera solanacearum. J. Nematol.* **8**: 284.

Godfrey, G.H. 1923. *Root-knot: Its Cause and Control.* USDA Farmers Bull. 1345.

Johnson, A.W. 1985. "Specific crop rotation effects combined with cultural practices and nematicides." In: *An Advanced Treatise on Meloidogyne* Vol. I: *Biology and Control* (J. N.Sasser & C.C. Carter, eds.). Coop. Publ. Dept. Plant. Path. North Carolina State Univ. and USAID Graphics. Raleigh, pp. 283-301.

Johnson, A.W. and Campbell, G.M. 1977. Influence of cropping system and a nematicide on *Meloidogyne* species in tomato transplant production. *J. Nematol.* **9**: 273-274.

Johnson, A. W. and Campbell, G.M. 1980. Managing nematode population densities on tomato transplants using crop rotation and a nematicides. *J. Nematol.***12**: 6-19.

Johnson, A.W., Sumdmer, D.R., Dowler, C.C. and Glaze, N.C. 1976. Influence of three cropping system and four levels of pest management on population of root-knot and lesion nematodes. *J. Nematol.* **8**: 290-291.

Jones, F.G.W. 1956. Soil population of beet eelworm (*Heterodera schachtii* Schm.) in relation to cropping. II. Microplot and field plot results. *Ann. appl. Biol.* **44**: 25-56.

Kanwar, R.S. 1989. Studies on cropping systems for management of root knot nematode *Meloidogyne javanica* (Treub) Chitwood. Ph.D. Thesis submitted to HAU, Hisar, pp.118+xx.

Kanwar, R.S. and Bhatti, D.S. 1992a. Controlling root-knot nematode *Meloidogyne javanica* through crop rotation. *Curr. Nematol.* **3**: 65-70.

Kanwar, R.S. and Bhatti, D.S. 1992b. Influence of cropping sequences on population behaviour of *Meloidogyne javanica* and crop yield. *Haryana agric. Univ. J. Res.* **22**: 40-45.

Kanwar, R.S. and Bhatti, D.S. 1993. Management of root knot nematode (*Meloidogyne javanica*) by poor host crops in three crop rotations. *Int. J. Pest Mgmt.* **39**: 304-308.

Kanwar, R.S. and Bhatti, D.S. 1994. "Cropping systems in the management of root knot nematodes." In: *Nematode Pest Management in Crops.* (D.S. Bhatti and R.K. Walia, eds.), CBS Publ., New Delhi, pp.118-132.

Kanwar, R.S. and Bhatti, D.S. 1994a. Crucifers and garlic (*Allium sativum*) as rotational crops in the management of *Meloidogyne javanica* in vegetable crops. *Indian J. agric Sci.* **64**: 339-342.

Kanwar, R.S. and Bhatti, D.S. 1998. Effect of length of crop rotation on the control of root-knot nematode *Meloidogyne javanica. Indian J. Nematol.* **28**: 213-215.

Khan, A.M., Saxena, S.K., Siddiqi, Z.A. and Upadhyay, R.S. 1975. Control of nematodes by crop rotation. *Indian J. Nematol.* **5**: 214-221.

Koen, H. 1966. Soil fumigation combined with susceptible cash crops to control root-knot nematodes (*Meloidogyne* spp.). *Nematologica* **12**: 109-112.

Mai, W.F. and Lownsbery, B.F. 1952. Crop rotation in relation to the golden nematode population of the soil. *Phytopathology* **42**: 345-347.

Noe, J.P. 1986. *Cropping Systems Analysis for Limiting Losses due to Plant-Parasitic Nematodes: Guide to Research Methodlogy.* Coop. Publ. Dept. Plant Pathol., North Carolina State Univ. and USAID, Graphics, Raleigh, pp.18.

Nusbaum, C.J. and Barker, K.R. 1971. "Population dynamics." In: *Plant Parasitic Nematodes.* Vol. I. (B.M. Zuckerman, W.F. Mai & R.A. Rohde, eds.), Academic Press, New York, pp. 303-323.

Nusbaum, C.J. and Ferris, H. 1973. The role of cropping systems in nematode population management. *Ann. Rev. Phytopath.* **11**: 423-440.

Okigbo, B.N. 1978. *Cropping systems and related research in Africa.* Association for the advancement of Agric. Sci. in Africa: Occasional Pub. Series OT-1, 81 pp.

Oostenbrink, M. 1961. Nematodes in relation to plant growth –II. The influence of the crop on the nematode population. *Neth. J. agric. Sci.* **9**: 55-60.

Oostenbrink, M. 1966. "Major characteristics of the relation between nematode and plants." *Meded. Landb. Hogesch.,* Wageningen **66**: 3-46.

Oteifa, B.A. and Elgindi, D.M. 1961. A critical method for evaluating tolerance limit in nematized host plants. *Plant Dis. Reptr.* **45**: 930-931.

Raymundo, S.A. 1985. "Cropping system research and root-knot nematode control." In: *An advanced Treatise on Meloidogyne* Vol. I. *Biology and Control* (J.N. Sasser & C.C. Carter, eds.), Coop. Publ. Dept. Plant Pathol., North Carolina State Univ. and USAID Graphics, Raleigh, pp. 277-281.

Riggs, R.D. and Winstead, N.N. 1959. Studies on resistance in tomato to root-knot nematodes and on the occurrence of pathogenic biotypes. *Phytopathology* **49**: 716-724.

Rodriguez-Kabana, R. and Touchton, J.T. 1984. corn and sorghum as rotational crops for the management of *Meloidogyne arenaria* in peanut. *Nematropica* **14**: 26-36.

Rohde, R.A. 1972. Expression of resistance in plants to nematodes. *Ann. Rev. Phytopath.* **10**: 233-252.

Sasser, J.N. and Nusbaum, C.J. 1955. Seasonal fluctuations and host specificity of root-knot nematode population in two year tobacco rotation plots. *Phytopathology* **45**: 540-545.

Seinhorst, J.W. 1967. The relationship between population increase and population density in plant parasitic nematodes. 3. Definition of the terms host, host status and resistance. 4. The influence of external conditions on the regulation of population density. *Nematologica* **13**: 429-442.

Smit. J.J. and Bos, W.S. 1976. "Root knot in northern Nigeria." In: *Proc. IMP Res. Plan. Conf. on Root-knot Nematodes, Meloidogyne* spp., IITA, Ibadan, Nigeria, pp. 40-43.

Somani, L.L. and Tikka, S.B.S. 1984. *Dictionary of Agriculture.* Agricole Publishing Academy, 456 pp.

Steiner, G. 1930. *Nemas causing plant galls controlled best through crop rotation.* USDA Year Book of Agriculture, pp.391-394.

Thorne, G. 1961. *Principles of Nematology.* McGraw-Hill Inc., New York, 553 pp.

Trivedi, P.C. and Barker, K.R. 1986. Management of nematodes by cultural practices. *Nematropica* **16**: 213-236.

Van Gundy, S.D. 1972. "Non chemical control of nematodes and root infecting fungi." In: *Pest Control Strategies for the Future. Nat. Acad. Sci.* USA, pp. 317-329.

Van Gundy, S.D., Peroz, B.J.G., Stolzy, L.H. and Thomason, I.J. 1974. A pest management approach to the control of *Pratylenchus thornei* on wheat in Mexico. *J. Nematol.* **6**: 107-116.

Vats, R. and Bajaj, H.K. 1998. "Role of weed and wild plants in the ecology and management of nematode pests of crops." In: *Plant Nematode Management – A Biocontrol Approach.* (P.C. Trivedi, ed.), CBS Publ., New Delhi, pp. 80-91.

Wilson, G.F. 1982. "Toward improved cropping systems for the humid tropics." In: *Proc. Third IMP Res. Plan. Conf. on Root-knot Nematodes. Meloidogyne* spp. Region IV and V, Ibadan, Nigeria. pp. 239-246.

❑❑❑

6

Nemic Problems in Maize and Their Management Strategies

A. N. Srivastava and Gautam Chawla

Introduction

Maize is one of the important cereal crops of the world. It holds a unique position in world agriculture ranking third after rice and wheat in terms of area as well as production. It also ranks third in importance among India's cereal crops covering nearly about 7 million hectares of land area and contributing over 14 million tons annually to the nation's foodgrain supply. However, maize productivity in India (1.9 t /ha) is still far less in comparison to the developed countries, the average world yield (4.9 t /ha). In India, maize is largely grown in Northern states where it serves as an important staple food for an economically vulnerable population of submountainarean and hilly regions. Maize also ranks first in importance as a feed and fodder crops for poultry and crossbreed cattle development respectively. Furthermore, it is an important source of raw material used in numerous industrial processes for making starch and alcohol and its byproducts like corn oil and confectionary goods.

The yield production of maize crop in India is greatly affected by several biotic and abiotic factors; prominent among them are fungi, bacteria, viruses, insects and nematodes. A large number of plant parasitic nematode species have been found to be associated with this crop in different parts of the world which accounts for considerable yield losses. However, the maize cyst nematode (*Heterodera zeae*), lesion nematodes (*Pratylenchus* spp.), sorghum cyst nematode (*Heterodera sorghi*), root-knot nematode (*Meloidogyne* spp.) and stunt nematode (*Tylenchorhynchus vulgaris*) are considered major nematode problems and important limiting factors in causing unthrifty growth of the crop, thus resulting in considerable economic loss in yield (Srivastava and Sethi, 1986a; Srivastava *et al.*, 1995; Srivastava, 2000; Srivastava *et al.*, 2001; Srivastava *et al.*,

2004). However, the maize cyst nematode, *Heterodera zeae* is considered the most important nematode problem in maize crop in India (Srivastava *et al.*, 1995). In the present research review article comprehensive information on nematode problems in maize and their management strategies are being discussed here.

Maize Cyst Nematode (*Heterodera zeae*)

Occurrence and Geographical Distribution

The maize cyst nematode, *Heterodera zeae* first reported from village Chapli, Udaipur district of Rajasthan, India by Koshy, Swarup and Sethi in 1970 on maize, is now known to be a widely distributed in major maize growing areas of northern, central, eastern and western parts of the country, especially Jammu & Kashmir, Himachal Pradesh, Uttaranchal, Punjab, Haryana, Delhi, Uttar Pradesh, Bihar, Jharkhand, Madhya Pradesh, Chhattisgarh, Rajasthan, Gujarat, Maharashtra and Andhra Pradesh (Koshy and Swarup, 1971; Srivastava and Swarup, 1975; Darekar *et al.*, 1981; Sharma *et al.*, 1984; Bajaj and Bhatti, 1984; Srivastava and Kaushal 1986; Makadia *et al.*, 1988; Khan *et al.*, 1989; Srivastava and Kaushal, 1991; Mani and Prakash, 1992). Besides, its widespread occurrence in India, the nematode has also been reported to occur in Egypt, Pakistan, USA, Thailand and Nepal (Aboul-Eid and Khorab, 1981; Maqbool, 1981; Sardenelli *et al.*, 1981; Chinnasri *et al.*, 1995; Sharma *et al.*, 2001). With the detection of this problematic nematode in western hemisphere especially from the American continent the importance of the nematode in limiting maize/corn production is more realised in world over.

Biology

The maize cyst nematode, *H. zeae* infects both *kharif* and *rabi* maize crop, however the damage to the crop by the nematode is high in *kharif* grown maize. The cysts of *H. zeae* are small in size, thin walled cuticle, light brown in colour, lemon shaped having well developed neck and vulva. A thin sub-crystalline layer is discernible in young cysts only. The majority of the eggs are retained in the body of the cyst that are easily visible from outside due to the thin walled cuticle of the cyst. Males are generally very sporadic and rare and not required for reproduction hence reproduction of *H. zeae* is by parthenogenesis (Hutzell,1984). Temperature plays an important role in the biology of *H. zeae* (Srivastava, 1980). A temperature of 25°C is most favourable for juvenile emergence (91% emergence) from the cysts (Srivastava and Sethi, 1985b). The emergence of larvae (J2) starts even before the females turn yellow or light brown and extends over several weeks and no maturity period is required for hatching of eggs.

However, there is no report on the influence of root exudates on the hatching of *H. zeae.* Similarly a temperature range of 25°-30°C is more favourable for embryonic and post-embryonic development of the nematode (Shahina & Maqbool, 1988). The development and reproduction of *H. zeae* is greatly influenced by soil temperature. Hutzell and Krusberg (1990) reported that optimum temperature for reproduction of *H. zeae* appeared to be 33°C under Maryland (USA) conditions. In India, the duration of life cycle of the nematode (*H. zeae*) is very short. The nematode completes its one life cycle in 17 to 20 days (J2 to J2) depending upon the maize cultivars and soil temperature (27-38°C). It has been speculated that *H. zeae* may complete 5-6 generations during one maize cropping season under Indian conditions (Srivastava & Sethi, 1985a). Soil type is very important environmental factor that influences the biology including reproduction of the nematode. The nematode prefers moderately light soil (sandy loam—sand mixture in the ratio 2:3) for its reproduction and multiplication and any addition of clay proportion to soil mixture results to a significant decline in the cyst production (Srivastava & Sethi, 1984a).

Host -Status

The maize cyst nematode, *H. zeae* reproduces and multiplies on economically important *kharif* and *rabi* cereals and millets. Besides, maize (*Zea mays*)—type host it also attacks wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), oats (*Avena sativa*), Italian or fox tail millet (*Setaria italica*), barnyard millet (*Echinochloa colona)*, and little millet (*Panicum* spp.) (Srivastava and Swarup, 1975). Some more graminaceous plants-*Coix lachryma, Eleucine coracona, Oryza sativa, Secale cereale, Zea mexicana* (Sharma & Swarup, 1984) and *Vetveria zizanioides* (Lal & Mathur, 1982) were also added to the host lists subsequently. Certain common *kharif* and *rabi* grasses and weed plants-*Archyranchus aspera, Cyperus rotundus, Dicera muricata, Eclipta prostata, Parthenium Hysterophorus, Tranthema pertulacestrum* and *Urochloa panicoidea* are also found to harbour the cyst population of *H. zeae*, though in small numbers in maize fields (Parihar *et al.*, 1991).

Pathogenicity/Disease Symptoms

The pathogenicity of the maize cyst nematode (*H. zeae)* has been established and demonstrated on maize in India by Srivastava (1980) and on corn in USA by Krusberg (1988). Srivastava & Sethi (1984) studied the relationship of initial population of *H. zeae* with plant growth of maize and nematode reproduction on Udaipur (Rajasthan) and Pusa (Bihar) populations and found that the plant growth reductions were directly correlated with initial nematode population densities. They also found that Pusa population was more virulent than Udaipur populations. The crops infected with *H. zeae* exhibit a poor,

patchy and unthrifty growth with stunting and pale yellow foliage. These symptoms generally confuse with those of nutrient deficiency symptoms. The infected root systems appear bushy and poorly developed which does not function properly. Also the diseased plants tassel earlier and bear smaller cobs with relatively fewer grains.

Economic Losses

The maize cyst nematode, *H. zeae* could cause an economic loss of about 12 to 26 per cent in maize cultivars Ganga-5 and Deccan-103 respectively in sandy loam soils under field conditions at research farm of IARI, New Delhi using carbofuran @ 2 kg a.i./ha with an average initial population of 5J2/cm^3 soil of *H. zeae* during *kharif* season (Anon, 1987). However, the crop losses due to this nematode at Udaipur (Rajasthan) and Pusa (Bihar) was estimated to be 29 per cent at 6J2/cm^3 soil in maize cv. Ganga Safed-2 and 17 per cent at 4J2/ cm^3 soil in local maize cultivar respectively. The crop loss experiments conducted at different fertility levels, under field and micro plot conditions during *kharif* season have clearly demonstrated that application of nitrogenous fertilizers mitigates the crop damage caused by *H. zeae* to some extent and enhances the plant growth and subsequently increases the maize yield to several folds (Anon., 1988, 1989).

Host-Parasite Relationship

The second stage juveniles (J2) of *H. zeae* penetrate the maize roots within 12 hrs of inoculation reaching maximum by 5th day (Srivastava & Sethi, 1985b). The meristematic and elongation zones are more preferred sites for larval penetration though penetration by J2 into maize roots takes place anywhere in the developing roots. Srivastava & Sethi (1984c) also reported that following root penetration by second stage juveniles, the endodermis wall becomes thick, the cytoplasm of pericycle and phloem cells becomes dense and granular and vascular bundles are pushed aside towards the endodermis resulting in the formation of 3 to 4 big and wide giant cells. The cortical cells are ruptured as third and forth stages of the nematode develop and subsequently distinct cavities are formed in which the nematode bodies are lodged. Further development of the nematode completely ruptures and disintegrates the surrounding cortical cells. Poly-nuclear conditions and irregular thickening of the giant cells produced by *H. zeae* have also been reported (Mishra *et al.*, 1995).

Population Dynamics and Survival

The population dynamics of the maize cyst nematode *(H. zeae)* studied in maize-cowpea-wheat rotation sequences revealed that the nematode population greatly fluctuates in the maize based cropping systems being followed and attains its high peak

populations in the October/November months which coincides with the maturity of the maize crop suggesting the host specific nature of the nematode (Srivastava and Sethi, 1986b). The fluctuations in the nematode population densities depends upon the prevailing soil temperature, moisture, crop sowing time and duration of the cropping season. They also observed that very little populations of J2 survived in the soil coinciding with the crop growth period being at non-detectable level during December to June months. It has been observed that the entire contents of the cyst do not empty out even in one year. So, this survival strategy of the nematode, coupled with the number of generations (5-6) during the crop season gives an indication of the damaging potential of this nematode. Moreover, *H. zeae* being multivoltine, it may obtain high reproduction potential and attain very high population densities. Similarly in Maryland (USA), eggs and/or juveniles inside cysts have been reported to survive in the field during winter months with no detectable mortality at different soil depths (Krusberg and Sardanelli, 1989).

Biotypes

Physiological variations have been recorded in the populations of *H. zeae* obtained from different geographical areas or within a region of the country. Ringer *et al.* (1987) indicated that *H. zeae* populations from Egypt, India and USA might differ in their abilities to reproduce on certain plants. Three biotypes of *H. zeae* have been distinguished in Egypt on the basis of different reproductive potential on some maize cultivars (Kheir *et al.*, 1989). In India, also three biotypes have been identified in Haryana (Ambala, Hisar and Sonepat) populations of *H. zeae* using vetiver and maize as host differentials (Bajaj and Gupta, 1994). The three identified biotypes are (i) multiplying on maize only (Ambala population), (ii) multiplying on vetiver only (Sonepat population), and (iii) multiplying on both maize and vetiver (Hisar population).

Association with Other Microorganisms

Associations of more than one population of ecto/endo-parasitic nematodes (root-knot and lesion) or soil fungi with *H. zeae* have been reported under field conditions. Often the disease symptoms have been reported to be aggravated in such complexes (Kaul and Sethi, 1982b). In a wilt disease complex including the fungus (*Cephalosporium thaydis*), the presence of *H. zeae* has been reported to cause enhanced wilting of the plants (Singh and Sitadhana, 1988). Similarly, interaction study of *H. zeae* with *Fusarium pallidoroseum* revealed that in prior inoculation of fungus, *H. zeae*, can cause greater damage to maize roots (Anon, 1983). Kaul and Sethi (1982a) reported that prior establishment of any of the nematode species *Heterodera zeae*, *Meloidogyne incognita*

and *Tylenchorhynchus vulgaris* either singly or in combination significantly reduced invasiveness of other species. Penetration by juveniles of both cyst and root-knot nematodes was more whenever they were inoculated earlier. Kaul and Sethi (1982b) also reported that individual effects of various nematode species occurring in mixed inoculations were not only modified by nematode species involved or host plant or prior establishment of any one species, but also by initial population densities of the nematodes involved in the interaction.

Management Strategies

Chemical

Several chemical control trials conducted at IARI research farm, New Delhi under field conditions and also at farmer's fields in different parts of the country using organophosphate and carbamate nematicides during recent past years for managing *H. zeae* populations through soil, seed and foliar spray treatments of nematicides have been reported to be very effective against populations of this nematode (Srivastava, 1980; Sethi and Srivastava, 1986; Srivastava and Sethi, 1989a, 1989b; Srivastava and Jagan Lal, 1997, 2004, Srivastava, 2004, 2005). Seed dressing with different organophosphate and carbamate nematicides both under pot and field conditions indicated enhanced emergence of juveniles of *H. zeae* while their penetration into maize roots was inhibited to considerable extent (Srivastava, 1980). Aldicarb used as 0.75 and 1.5 per cent and fensulfothion @ 0.25 and 0.5 per cent were found to be more effective in reducing the populations of *H. zeae* (Sethi and Srivastava, 1985). Similarly Kaul and Sethi (1987b) also reported the effect of some systemic nematicides on the emergence of the larvae from the cysts of *H. zeae* and found that cysts when exposed to five different concentrations (62.5 to 500 µg/ml) of aldicarb, carbofuran, oxamyl and phenamiphos or an increase in the exposure time from 3-15 days resulted in decreased emergenge of larvae from the cyst. However, phenamiphos was proved to be most effective nematicide in reducing juvenile emergence *in vitro*.

In yet another study Sethi and Kaul (1987b) reported that root invasion was least when juveniles of *H. zeae* were exposed to carbofuran @ 10 µg/ml concentrations for 6 hours. Foliar spray of maize plants with phenamiphos @ 250 or 500 µg/ml 3 days prior to nematode inoculation was found more effective than post inoculation sprays (Kaul and Sethi, 1987b).

Carbosulfan (25 ST) used as seed treatment @ 2-3% (w/w) and soil application of carbofuran (3G), phorate (10G) and sebuphos (10G) @ 2Kg a.i/ha have also been

found to be very effective in reducing nematode populations and subsequently increasing the crop yield (Srivastava and Sethi, 1989a, 1989b). The pre-sowing soil applications of phenamiphos resulted in higher reduction of cyst production of *H. zeae* than other chemicals (Kaul and Sethi, 1988a, 1988b). The carbosulfan seed treatment accompanied with carbosulfan foliar spray treatment resulted in additional control of the nematode (Srivastava and Sethi, 1989b; Srivastava and Jagan Lal, 1997, 2004). The potential of carbosulfan seed treatment proved to be very effective and economical management strategies for reducing the total requirement (80 to 100g carbosulfan required for treating 1kg of maize seeds) as also the cost of the chemicals against *H.zeae* on maize.

The treatment of neem based products/formulations namely neem seed kernel powder and achook powder as seed dressing @ 5 and 10 % also reduced the population of *H. zeae* to some extent but enhanced the crop growth of maize considerably (Srivastava, 2004).

Even though, carbofuran, phorate, sebuphos and carbosulfan are quite effective and capable in containing the population densities of *H. zeae* and thus thereby enhancing plant growth and subsequently increasing the crop yield, their use in crops like maize may not be favoured by the farmers, particularly since maize is not as remunerative crop as other cereal crops such as rice and wheat and hence nematode management strategies for maize must be based on some other approaches preferably non-chemical methods like crop rotation and nematode resistant cultivars which have been proved to be quite effective against other cyst nematodes under experimental conditions. Perhaps a combination/integration of different approaches including soil organic amendments and biocontrol agents may be useful for developing the integrated management schedule for this nematode.

Non-Chemical Management Strategies

Cultural:

Crop Rotations

There is a good scope for adopting/using crop rotation as a management strategy for maize cyst nematode, *H. zeae* as host range of this nematode is limited and restricted to only graminaceous plants. Since *H. zeae* is host specific, monoculturing of maize and other host crops in the same field should be avoided, as it is likely that under continuous maize cropping systems, nematode populations may increase considerably, ultimately resulting in significant yield loss. Hence, two years rotation with non-host crops

(preferably non-cereals like vegetables, pulses and oilseeds) can be fruitful, as it would bring down the nematode populations below economic threshold levels.

Deep/Summer Ploughing

Summer fallowing and keeping the fields free from grasses and weed plants can also help in checking the survival and perpetuation of *H. zeae* population in off seasons. Two to three deep ploughing at 10-15 days interval during April/May months in hot summer also reduces the nematode populations as also the growth of grasses/weed plants a considerable extent.

Resistant Varieties

The use of resistant and tolerant varieties is the most effective and economical management strategy for plant parasitic nematodes. Though resistant sources in maize crop against maize cyst nematode, *H. zeae* are not yet available, however, there are still few cultivars available, which can provide some degree of resistance against this nematode. Maize cultivars Ageti-76 and Karnal-1 have been found to be moderately resistant against *H. zeae* in Haryana, India. Similarly, in Pakistan Sharad White, Gauhar, Azam and Composite-15 maize varieties have shown moderately resistant reactions against *H. zeae* (Shahina *et al.*, 1989).

Organic Soil Amendments

The use of oil cakes and other organic soil amendments have been proved effective in managing the populations of *H. zeae*. Field trials using various soil organic amendments against this nematode have clearly indicated that combination of mustard cake and tobacco dust @ 2.5 q/ha, -a practice adopted by farmers in the eastern parts of the country is as efficient as carbofuran soil treatment @ 2 kg a.i./ha in terms of increased crop yield and suppression of the nematode populations of *H. zeae* (Anon, 1987). The practice can serve as one of the important components of integrated approach for this nematode and can easily be adopted by the farmers of other regions of the country.

Biocontrol Agents

Although there is no systematic work on use of biocontrol agents against maize cyst nematode (*H. zeae*) however, certain nematophagus fungi such as *Cataneria, Verticillium* and *Gleocladium* have been isolated from cysts of *H. zeae.* Srivastava (2005) reported that bioagents, *Pseudomonas fluorescens* used @ 5 and 10% w/w though reduced the cyst population of *H. zeae* to some extent but was not as efficient as carbofuran and sebuphos in containing the population of the nematode. Also

Arthobotrytis coincides and *Monacrosporium salinum* have shown some potential to kill second-stage juveniles of *H. zeae in vitro* (Anon, 1987), but their real potential as biocontrol agent is still to be exploited and explored for the management of this nematode.

Lesion Nematodes (*Pratylenchus* spp.)

The root lesion nematodes, *Pratylenchus* spp. are most economically important phytonematodes of maize crop. They are cosmopolitan and consistently found associated with maize crop wherever it is grown. Eventhough several species of root lesion nematodes namely *P.brachyurus, P. zeae* and *P. penetrans* are reported to be associated with poor growth of maize in tropical and sub-tropical areas of the world, *P. zeae, P. thornei* and *P. delattrei* are considered important on maize in India.

Biology and Disease Symptoms

Even though the root lesion nematode, *P. zeae* is economically important and most frequently encountered species in maize fields in India (Pall and Chand, 1971) but the above ground symptoms produced by the nematode are not very specific. Maize plants infected with *P. zeae* show poor and stunted plant growth, reduced root and shoot weight and leaf chlorosis. Nematode damage to the fibrous root systems results in extensive destruction of cortical parenchyma, severe root pruning and proliferations of lateral roots. Mechanical breakdown of cells and necrosis of stelar and cortical tissues resulting in formation of cavities are also attributed to nematode damage. The presence of small brown to black lesions on the root surface is the most important symptoms/damage produced by the lesion nematodes.

Temperature, soil type, moisture and tillage operations are important environmental factors which greatly affect the development and reproduction of nematode species as well as disease development. Higher temperature (30°C) is mostly preferred by *P. zeae* for its reproduction while by *P. brachyrus* and *P. penetrans* favour for their penetration and development. Soil type and tillage operations have also been reported to affect lesion nematode population dynamics. Most *Pratylenchus* species thrive well in a wide range of soil types but Naganathan and Sivakumar (1975, 1976) reported higher population densities of *P. delattrei* in black sandy loam soil and brown sandy clay loam soil than in any other soil type. Moisture is another important factor, which affects the development of species of lesion nematodes. Damage to the maize plants, on the other hand, increase with decreasing moisture levels. *P. thornei* is also fairly common in maize fields, sometimes occurring concomitantly with *P. zeae* under green gram maize chickpea sequence.

Economic Losses and Management Strategy

Exact economic lossess caused by the lesion nematodes have not been made possible under field conditions due to presence of mixed population of the nematode in the field. Also precise evaluations of losses in maize by lesion nematodes are hampered by secondary infection of nematode lesions by fungi and bacteria (Egunjobi, 1974). However, significant reduction in plant growth following inoculation of *P. zeae* and *P. thornei* are direct evidence of the role played by the nematodes obtained under greenhouse conditions.

The population densities of lesion nematodes may increase considerably under continuous maize cropping ultimately resulting in significant yield losses (Maqbool and Hashmi, 1986; Riversat and Germani, 1985). Also, lesion nematodes have wide host range, which can affect the selections of crop used to control the nematode in crop rotation sequences. In addition, the presence of weed hosts in a field can strongly influence lesion nematode densities in maize fields (Egunjobi, 1974; Stradioto *et al.*, 1983). Yield increase of 33 to 128 per cent have been obtained following the application of nematicides (Walters, 1979). Bergeson (1978) and Norton *et al.* (1978) also reported that treatment with nematicides increased crop yield by 10 to 54 per cent. Lordello *et al.* (1983) also observed yield increase of more than two folds after nematicide treatment. Similarly in Nigeria *P. brachyurus* has been reported to be responsible for 28.5 per cent yield reduction. The reduction in yield was correlated with a 50 per cent increase in nematode density (Egunjobi, 1974).

Association with Other Microorganisms

The association of other microorganisms in disease complex in crop loss of maize caused by lesion nematodes has not been studied fully. However, Nath *et al.* (1978) found that the inoculations of maize plant with *P. zeae* either alone or in combination with the maize-mosaic virus showed that the effect of pathogen was greatest when the nematode and virus were inoculated simultaneously or when nematode inoculation preceded 7 days the virus inoculation.

Root-Knot Nematodes (*Meloiogyne* spp.)

The root-knot nematodes (*Meloidogyne* spp.) are another important nematode problem in maize crop in India.The association of root-knot nematode (*Meloidogyne africana*) with maize crop was first reported from India by Chitwood and Toung (1960). Krishnamurthy and Elias (1967) also recorded maize as a host of *M. incognita*. Though association of *M. incognita, M. javanica, M. africana, M. arenaria* and *M.hapla* have

been recorded on maize, two species namely *M.incognita* and *M. javanica* have been reported damaging maize crop in almost all the maize growing regions of the country.

Biology and Disease Symptoms

Although both species *M. incognita* and *M. javanica* are frequently encountered in maize fields, information on their biology, nature of damage, economic losses and management on maize is meager. However, indirect observations suggest that these species are of economic importance. Pathak and Yadav (1980) observed significant reduction in shoot and root weights of maize plants at the initial inoculum level of 2J2/g of soil though no grain yield loss was reported. They also reported yellowing of leaves and patchy growth of plants. The above ground symptoms produced by root-knot nematode on maize include stunting of infected plants, leaf chlorosis and patchy growth. The root galls produced by the root-knot nematode are often small, terminal or sub-terminal. The nematode completes its one life cycle in about 30 days. Four races have been identified in *M. incognita* that reproduces well on maize with some cultivars exhibiting specificity to a specific race (Oteifa and Elgindi, 1982; Lopez, 1981).

Association with Other Microorganisms

Simultaneous inoculations of *M. incognita* and maize-mosaic-virus resulted in severe losses in maize as compared to the prior inoculation of nematode on either of the pathogen alone (Khurana *et al.*, 1970). Similarly Goswami and Raychaudhari (1978) in an interaction study between mosaic virus and *M. incognita* found that the mosaic symptoms appeared earlier and nematode reproduction was greater when both pathogens were together than when alone.

Sorghum Cyst Nematode (*Heterodera sorghi*)

The sorghum cyst nematode (*H. sorghi*) was first detected and described on the roots of sorghum crop from Ghaziabad and Allahabad districts of Uttar Pradesh by Jain, Sethi, Swarup and Srivastava in 1982. It was also later found to infect maize and rice. Srivastava and Sethi (1987) reported maize to be highly preferred host supporting high number of cyst population of *H. sorghi*. The nematode is reported to occur and widespread in the northern, western and southern states especially Jammu & Kashmir, Himachal Pradesh, Haryana, Punjab, Delhi, Andhra Pradesh and Maharashtra (Dhawan *et al.*, 1983; Sakhuja and Singh, 1985; Srivastava and Kaushal, 1986; Bajaj and Walia, 1986; Sharma and Sharma, 1988; Darekar *et al.*, 1990).

Even though there is no field data available on exact yield losses caused by *H. sorghi* in maize, experimental work carried out in green house conditions indicates

significant reduction in growth of Deccan-103 maize. Srivastava and Chawla (1990) reported an inoculum level of 4 J2/g of soil of *H. sorghi* as an economic threshold level on maize cultivar Deccan-103. They also reported that *H. sorghi* is more pathogenic to maize as compared to sorghum on which nematode was first reported. The nematode (*H. sorghi)* requires 30°C temperature for its larval emergence and completes its one-generation (J2 to J2) in 24 days at 28-36°C temperature on maize and in a crop season more than four generations are completed during *kharif* season (Srivastava and Chawla, 1991). The nematode reproduces and multiplies on important *rabi* and *kharif* cereals like barley, wheat, rice and pearl millet. Chawla and Srivastava (1995, 2005) reported maize cultivars D-765, D-851, Navin, R-17, VL-88 and W-101 as moderately resistant against sorghum cyst nematode, *H. sorghi* with reproduction factor (Rf) 0.96 to 3.8.

Stunt Nematode (*Tylenchorhynchus* spp.)

Among the several species of the stunt nematode, *Tylenchorhynchus vulgaris* appears to be most important among the several species of stunt nematodes reported to be associated with the maize crop. The species first described from maize by Upadhyay *et al.* (1972a) occurs most frequently in the sandy loam soils of Andhra Pradesh, Bihar, Delhi, Haryana, Himachal Pradesh, Punjab, Rajasthan and Uttar Pradesh (Upadhyay and Swarup, 1976).

Even though *T. vulgaris* has a wide host range, the most suitable hosts belong to the Graminae family. The nematode completes its one life cycle between 25-27 days at 25-30°C temperature (Upadhyay *et al.,* 1972a) while it took 15-18 days (egg to egg) on maize cultivar Ganga-5 (Siyanand *et al.,* 1982). A population level of 1000 or more nematodes per kg of soil was found to adversely affect plant growth (Upadhyay and Swarup, 1981). However, Jain (1982) reported *T. vulgaris* to be more pathogenic at 10000 inoculum level where reduction in shoot and root length and fresh and dry weight was maximum in all the seven maize cultivars tested. Upadhyay and Swarup (1972) also reported loam, clay loam and sandy loam soils to be most suitable for nematode reproduction.

Significant reduction in plant growth of maize was obtained when *T. vulgaris* was inoculated in combination with *P. zeae* or *Fusarium monoliforme* than when either of the organisms was inoculated alone. However, the multiplication of the nematode was not significantly affected in the presence of *P. zeae* of *F. monoliforme* (Upadhyay and Swarup, 1981).

The seed treatment of carbofuran was found very effective for initial protection of maize seedlings in field plots predominantly inhibited with *T. vulgaris* and the

subsequent build up of nematodes could be prevented by granular applications in soil (Singh and Bindra, 1978).

Lance Nematode (*Hoplolaimus* spp.)

The lance nematode (*Hoplolaimus indicus*) is another important and the most frequently encountered nematode pest associated with maize crop (Haider and Nath, 1992). Maize plants showing stunted and patchy growth were observed harboring large populations *of H. indicus*. Significant growth reductions and stunting of maize plants has been recorded at 100 nematodes/500 g of soil. The nematode acts as a vagrant endoparasite causing root lesions, thickening of cell wall and formation of tunnels in the cortical region. One life cycle (egg to egg) of *H. indicus* is completed between 39-43 days on maize cv. Ganga-5 at 30°C ± 2°C (Siyanand *et al.,* 1982). In a population dynamic study, the population densities of *H. indicus* was observed to be highest in the month of October while it was lowest in June. The availability of feeder roots and temperature are important factors for population build-up of this nematode (Haider and Nath, 1992).

The infection of *Fusarium monoliforme* on maize roots parasitized with *H. indicus* aggravated the root damage. In combined inoculations the plant showed minimum top growth and maximum disease symptoms (Nath *et al.,* 1974). After 60 days the plant were prone to wilting during daytime. Mukhtar *et al.* (1993) reported that the severity of disease increased when nematode inoculum followed seven days after inoculation of soil with *F. monoliforme*.

Conclusion

The maize cyst nematode, *Heterodera zeae* is the most serious nematode problem in India. The nematode is widely distributed in maize major growing areas of northern, central, western and eastern states of India. Its presence at higher altitude in northern hills, especially in Jammu & Kashmir and Himachal Pradesh needs immediate attention to study the role played by this nematode in limiting maize production in the country. So far, the nematode has not been recorded from Karnataka, a southern state, even though maize productivity is very high in this state. But it is possible that with the ongoing extensive survey programme, the nematode may be encountered in the near future. Further, maize growing areas of North-eastern states of the country such as Assam, Meghalaya, Manipur and Sikkim also need to be explored for the presence of this nematode species.

The other cyst nematode species (*H. sorghi)* is not a field problem on maize now but has the potential to damage the crop in near future. Therefore a special care and

caution has to be taken while formulating the crop rotation sequences for managing maize nematodes.

The results on various chemical trials have clearly shown that carbosulfan seed treatment and soil application of carbofuran, phorate and sebuphos enhances the crop growth and subsequently increases the yield with considerable reduction in the population of maize cyst nematode, *H. zeae.* Further work on this aspect with reference to cost-benefit ratio is needed. However, recommendations of high cost technology involving use of nematicides, may not find favour with the farmers particularly because maize is not a high value crop as rice and wheat and hence nematode management technology for maize must be based on non-chemical methods particularly crop rotation and nematode resistant cultivars. It is likely that under continuous maize cropping populations of *H. zeae* may increase considerably, ultimately resulting in significant yield losses. Therefore, monoculture of maize and other host crops should be avoided. Two years rotations with non-host crops preferably non-cereals like vegetables, pulses and oil seeds can be fruitful, as it would bring down the nematode population below economic threshold level appreciably. Further, screening of maize genotypes work should largely be taken up to identify the sources of resistance/tolerance against *H. zeae* and also other nematodes on maize crop. Investigations are also needed to work out the influence of various soil organic amendments generally adopted by farmers for their incorporation in economically viable integrated management of the nematodes. The possibilities for exploitation of bioagents should also be explored for managing the problematic nematodes of maize crop.

References

Aboul-Eid, H.Z. and Ghorab, A.I. (1981). The occurrence of *Heterodera zeae* in maize fields in Egypt. *Egyptian J. Phytopathology* **13**: 51-61.

Anonymous (1987). *First Annual Technical Report, PL-480 Project; FG-In-673 (IN-ARS-326)*, 31pp.

Anonymous (1988). *Second Annual Technical Report,PL-480 Project;FG-In-673(IN-ARS-326)*, 43pp.

Anonymous (1989). *Final Technical Report, Pl-480 Project; FG-In-673 (IN-ARS-326)*, 48pp.

Anonymous (1993). *Final Technical Report I.C.A.R. Cess Fund Scheme, F.No. 2-5/85*-pp, 32pp.

Ahmed, S.I. and Qasim, M. (1900). A survey of corn cyst nematode in North-west frontier province and in northern areas of Pakistan. *International Nematology Network Newsletter* 7: 26-27.

Bajaj, H.K. and Bhatti, D.S. (1984). Occurrence of *Heterodera zeae* in Haryana state, India. *Haryana Agri. Univ. J. Res.* **14**: 551.

Bajaj, H.K. and Gupta, D.C. (1994). *Fundamental Applied Nematol.* **17**: 1389-1390.

Bergeson, G.N. (1978). Control of the lesion nematode (*Pratylenchus* spp.) in corn with carbofuran. *Pl. Dis. Reptr.* **62**: 295-297.

Chawla, G. and Srivastava, A.N. (1995). Response of certain maize cultivars to *Heterodera sorghi. Indian J. Nematol.* **25**: 28-29.

Chawla, G. and Srivastava, A.N. (2005). Reaction of maize varieties to *Heterodera sorghi. Ann. Pl. Protec. Sci.* **13**: 199-201.

Chinnasri, B, Tangchitsomkid, N. and Toida, Y. (1995). *Japanese J. Nematol.* **24**: 35-38.

Chitwood, B.G. and Toung, MO-Chu (1960). *Meloidogyne* from Taiwan and New Delhi. *Phytopathology.* **50**: 631-632.

Darekar, K.S., Kadam, M.V., Ayri, D.S. and Dorge, S.K. (1981). Occurrence of maize cyst nematode, *Heterodera zeae* in Maharashtra state. *J. Maharashtra Agri. Univ.* **6**: 156.

Egunjobi, O.A. (1974). Nematodes and maize growth in Nigeria. L. Population dynamics of *Pratylenchus brachyurus* in about the roots of maize and its effect on maize production at Ibadan. *Nematologica* **20**: 91-93.

Goswami, B.K. and Ray Chaudhuri, S.P. (1978). "Interaction of root-knot nematodes and viruses in maize and tobacco in India." *International Congress of Plant Pathology* (3ed.). G.F.R. 16-13 August.

Haider, M.G. and Nath, R.P. (1992). *Curr. Nematol.* **3**: 173-177.

Hutzell, P.A. (1984). Description of males of *Heterodera zeae. J. Nematol.* **16**: 83- 86.

Hutzell, P.A. and Krusberg, L.R. (1990). Temperature and the life cycle of *Heterodera zeae. J. Nematol.* **22**: 414-417.

Ibrahim, I.K.A., Rezk, M.A. and Ibrahim, A.A.M. (1986). Occurrence of the cyst nematodes *Heterodera avenae, H. daverti* and *H. rosii* in northern Egypt. *J. Nematol.* **18**: 614.

Jain, K.K., Sethi, C.L., Swarup, G. and Srivastava, A.N. (1982). *Heterodera sorghi* sp.n. a new cyst forming nematode parasitising sorghum. *Revue Nematol.* **5**: 201-204.

Kaul, R.K. and Sethi, C.L. (1982a). Effect of simultaneous inoculations and prior establishment of *Heterodera zeae, Meloidogyne incognita* and *Tylenchorhynchus vulgaris* on penetration of cyst and root- knot nematodes into maize roots. *Indian J. Nematol.* **12**: 79-85.

Kaul, R.K. and Sethi, C.L. (1982b). Interaction amongst Heterodera zeae, Meloidogyne incognita and Tylenchorhynchus vulgaris on Zea mays. *Indian J. Nematol.* **12**: 91-98.

Kaul, R.K. and Sethi, C.L. (1987a). Effect of some systemic nematicide on the *in vitro* emergence of larvae from the cysts of *Heterodera zeae. Indian J. Nematol.* **17**: 214-217.

Kaul, R.K. and Sethi, C.L. (1987b). Penetration and development of *Heterodera zeae* in *Zea mays* as influenced by foliar spray of phenamiphos and oxamyl. *Indian J. Nematol.* **17**: 237-240.

Kaul, R.K. and Sethi, C.L. (1988a). Effect of time of application of certain systemic nematicides on final cyst production and fecundity of *Heterodera zeae. Indian J. Nematol.* **18**: 134-135.

Kaul, R.K. and Sethi, C.L. (1988b). Soil application of systemic nematicides in relation to emergence, penetration and development of *Heterodera zeae. Indian J. Nematol.* **18**: 1-5.

Khan, E. Gaanguly, S. and Lalita, Y. (1989). New records on the occurrence of cyst nemaodes in India. *Int. Nematol. Network Newsl.* **6**: 19-20.

Khair, A.M., Farahat, A.A. and Abadir, S.K. (1989). "Studies on the corn cyst nematode (CCN) *Heterodera zeae* in Egypt," IV Variation in development and reproduction of four different populations of some corn cultivars.

Khurana, S.M.P., Goswami, B.K. and Raychaudhary, S.P. (1970). Interaction of maize mosaic with root-knot nematode, *Meloidogyne incognita* in maize (*Zea mays* L.). *Phytopath. Z.* **69**: 267-272.

Koshy, P.K., Swarup, G. and Sethi, G.L. (1970). *Heterodera zeae* n.sp. (Nematoda: Heteroderidae) a cyst forming nematode on *Zea mays. Nematologica* **16**: 511-516.

Koshy, P.K., Swarup, G. (1971). Distribution of *Heterodera avenae, H. zeae, H. cajani* and *Anguina tritici* in India. *Indian J. Nematol.* **1**: 106-111.

Krishnamurthy, C.V.C. and Elias, N.A. (1967). Host range of *Meloidogyne incognita* causing root-knot on tobacco in Hansur, Mysore state. *Indian Phytopathology* **20**: 374- 377.

Krusberg, L.R. (1988). "The corn cyst nematode, *Heterodera zeae* in the United States." In: *Advances in Plant Nematology*, 171-175.

Krusberg, L.R. and Sardanelli, S. (1989). Survival of *Heterodera zeae* in soil, field and in the laboratory. *J. Nematol.* **21**: 347-355.

Lal, A. and Mathur, V.K. (1982). Occurrence of *Heterodera zeae* on *Vetiveria zizanioides. Indian J. Nematol.* **12**: 405-407.

Lopez, R. (1981). Informe sobre las investigations realizadas en la imversided de Casta Rica Como parte del proyecto Internacional *Meloidogyne* Memories de la segunda conferencia regional de planlamiento del Proyecto. *Internacional Meloidogyne Region I. Panama*: 16-22.

Lordello, R.R.A., Sawazaki, F., lordello, A.I.L. and Sobrinho, J.A. (1983). Control of *Pratylenchus* spp. on maize with systemic nematicides and castor bean cake. *Sociedade brasileira de Nematologica.* 241-250.

Makadia, B.M., Jagani, D.K. and Patel, D.J. (1988). Occurrence of *Heterodera zeae* on maize in Gujarat. *Indian J. Nematol.* **18**: 130.

Maqbool, M.A. (1981). Occurrence of root - knot and cyst nematodes in Pakistan. *Nematol. Medit.* **9**: 211-212.

Maqbool, M.A. and Hashmi, S. (1986). Population trends of parasitic nematodes in different cropping sequences and the effect on yield of corn cv. AZAM. *Int. Nematol. Network, NEWSL.* **3**: 34-38.

Mishra, S.N., Edward, J.C. and Gupta, P. (1985). Histopathology of *Heterodera zeae* on maize. *Indian J. Nematol.* **15**: 111-112.

Mukhtar, J., Khan, A.A. and Lal, S. (1993). *Nematol. Medit.* **21**: 151-153.

Naganathan, T.G. and Sivakumar, C.V. (1975), Host parasite relationships and influence of soil types on the lesion nematode, *Pratylenchus delattrei* Luc, 1958 on maize, *Indian J. Nematol.* **5**: 162-169.

Naganathan, T.G. and Sivakumar, C.V. (1976), Control of the lesion nematode, *Pratylenchus delattrei* Luc, 1958 on maize, *Indian J. Nematol.* **6**: 32-38.

Nath, R.P., Haider, M.G. and Prasad, S.S. (19740. Combined effect of *Hoplolaimus indicus* and *Fusarium moniliforme* on maize plant. *Indian J. Nematol.* **4**: 90-93.

Nath, R.P., Swarup, G., Prasad, S.S. and Prasad, A.B. (1978). *Indian Phytopath.* **31**: 307-309.

Norton, D.C. Tollefson, J., Huiz, P. and Thomas, S.H. (1978). Corn yield increases relative to non-fumigant chemical control of nematodes. *J. Nematol.* **10**: 160-166.

Oteifa, B.A. and Elgindi, D.M. (1982). Relative susceptible of certain commercially important cultivars to existing biotypes of *Meloidogyne incognita* and *M javanica* Nile-Delta, Egypt. Proceedings of the third research and planning conference on root-knot nematodes, *Meloidogyne* spp. Region VII Coimbra, Portugal: 157-159.

Parihar, Aruna, Yadav, B.S. and Siddiqui, A.U. (1991). Reaction of some cultivated and weed plants to the corn cyst nematode, *Heterodera zeae. Indian J. Nematol.* **21**: 94-95.

Pathak, A.K. and Yadav, B.S. (1980). *Indian J. Mycol. Plant Pathol.* **10**: 11.

Reversat, G. and Germani, G. (1985). Recherches sur la pathogenic des nematodes assicies aug mais four rager an Senegal. *Revue de Nematologie.* **8**: 27-30.

Ringer, C.E., Sardanelli, S. and Krusberg, L.R. (1987). Investigations of the host range of the corn cyst nematode, *Heterodera zeae* from Maryland. *Annals of Applied Nematology* **1**: 97-106.

Sardanelli, S., Krusberg, L.R. and Golden, A.M. (1981). "Corn cyst nematode, *Heterodera zeae* in the United States." *Plant Disease* **65**: 622.

Shahina, F., Abid, M. and Maqbool, M.A. (1989). Screening for resistance in corn cultivars against *Heterodera zeae. Pakistan J. Nematol.* **7**: 75-79.

Shahina, F. and Maqbool, M.A. (1989). Embryonic and post-embryonic development stages of *Heterodera zeae* Koshy *et al.*, 1970 on *Zea mays. Pakistan J. Nematol.* **7**: 3-16.

Sharma, N.K., Damanjeet and Sharma, S. B. (1984). Incidence of maize cyst nematode, *Heterodera zeae* in Himachal Pradesh. *Indian J. Nematol.* **14**: 198.

Sharma, S.B. and Swarup, G. (1984). "Cyst forming nematodes of India." *A falcon book from Cosmo publications,* New Delhi, India, 152 pp.

Sethi, C.L. and Kaul, R.K. (1987). Nematicidal exposure of larvae of *Heterodera zeae* and their development in maize roots. *Indian J. Nematol.* **17**: 261-263.

Singh, I. and Bindra, O.S. (1978). Effect of carbofuran as seed treatment and granular soil treatment alone and in combination on nematodes associated with maize. *Indian J. Nematol.* **8**: 89-91.

Singh, S.D. and Siradhana, B.S. (1988). Effect of nematodes on late wilt of maize. *Indian Phytopath.* **41**: 173-176.

Siyanand, Seshadri, A.R. and Dasgupta, D.R. (1982). Investigation on the life cycle of *Tylenchorhynchus vulgaris, Pratylenchus thornei* and *Hoplolaimus indicus* individually and in combined infestations in maize. *Indian J. Nematol.* **12**: 272-276.

Srivastava, A.N. (1980). Studies on the maize cyst nematode, *Heterodera zeae.* Ph.D. Thesis, Post Graduate School, IARI, New Delhi. pp 99.

Srivastava, A.N. (2002). Nematode diseases of maize and their management in India. Lead paper presented in *"Symposium on Major Plant Diseases and their Management"* held during October 29- 30, 2002 at Central Institute for Cotton Research, Nagpur (Maharashtra).p.16.

Srivastava, A.N. (2004). Management of maize cyst nematode, *Heterodera zeae* with chemicals and botanicals. Paper presented in *"National Symposium on Pesticides: Myths, Realities and Remedies"* held during December 1-3, 2004 at New Delhi. p. 52.

Srivastava, A.N. (2005). Nematicidal efficacy of chemicals, botanicals and bioagents against maize cyst nematode, *Heterodera zeae.* Paper presented in *"National Symposium on Bio-pesticides"* held during April 20-21, 2005 at New Delhi. p. 52.

Srivastava, A.N. and Chawla, G. (1990). Pathogenicity and reproduction of *Heterodera sorghi* on *Zea mays. Indian J. Nematol.* **20**: 202-206.

Srivastava, A.N. and Chawla, G. (1991). Life cycle of *Heterodera sorghi* on maize. *Indian J. Nematol.* **21**: 153-155.

Srivastava, A.N. and Chawla, G. (2004). Effect of some systemic nematicides on *Heterodera sorghi* infecting maize. Paper presented in *"National Symposium on Paradigms in Nematological Research for Biodynamic Farming"* held during November 17-19, 2004 at University of Agricultural Sciences, GKVK, Bangalore (Karnataka). p.106- 107.

Srivastava, A.N. and Gopal Swarup (1975). Preliminary studies on some graminaceous plants for their susceptibility to the maize cyst nematode, *Heterodera zeae* Koshy *et al.,* 1970. *Indian J. Nematol.* **5**: 257-259.

Srivastava, A.N. and Jagan Lal (1993). Effect of split application of carbofuran and sebuphos on development of *Heterodera zeae* and growth of *Zea mays. Indian J. Nematol.* **23**: 20-21.

Srivastava, A.N. and Jagan Lal (1997). Effect of carbosulfan and sebufos applied singly and in combination on reproduction of *Heterodera zeae* and growth of *Zea mays. Ann. Pl Protec. Sci.* **5**: 94-97.

Srivastava, A.N. and Jagan Lal (2004). Effect of carbofuran and carbosulfan following soil, seed and foliar application on plant growth of maize and reproduction of maize cyst nematode, *Heterodera zeae*. *Indian J. Nematol.* **34**: 200-204.

Srivastava, A.N. and Kaushal, K.K. (1986). "Occurrence and distribution of *Heterodera zeae* and *H. sorghi* in India." *Nat. Conf. Plant Parasitic Nematodes*, New Delhi, 1986, p.34.

Srivastava, A.N. and Kaushal, K.K. (1991). *Heterodera zeae*, at high altitudes in Himachal Pradesh. *Indian J. Nematol.* **21**: 163.

Srivastava, A.N., Kaushal, K.K. and Khajan Singh (2001). Bio-diversity in plant parasitic nematodes in maize- wheat based cropping systems. Paper presented in "*National Congress on Centenary of Nematology in India- Appraisal ad Future Plans*" held during December 5-7, 2001 at New Delhi. p.86.

Srivastava, A.N., Kaushal, K.K. and Khajan Singh (2004). Nematode bio-diversity in maize-wheat/ millet- wheat cropping systems in Himachal Pradesh. Paper presented in "*National Symposium on Paradigms in Nematological Research for Biodynamic Farming*" held during November 17-19, 2004 at University of Agricultural Sciences, GKVK, Bangalore (Karnataka). p. 19.

Srivastava, A. N., Hanuman Singh and Verma, A, C. (2001). Nematode diseases of maize and millets and their management. Lead paper presented in "*National Congress on Centenary of Nematology in India- Appraisal ad Future Plans*" held during December 5-7, 2001 at New Delhi. p. 24-25.

Srivastava, A. N. and Sethi, C. L. (1984a). Effect of soil type on reproduction of *Heterodera zeae*. *Indian J. Nematol.* **14**: 72.

Srivastava, A. N. and Sethi, C. L. (1984b). Relationship of initial population of *Heterodera zeae* with plant growth of maize and nematode reproduction. *Indian J. Nematol.* **14**: 110-114.

Srivastava, A. N. and Sethi, C. L. (1984c). Histopathology of maize roots infested with maize cyst nematode, *Heterodera zeae*. *Indian J. Nematol.* **14**: 205-206.

Srivastava, A. N. and Sethi, C. L. (1985a). On the larval penetration and biology of *Heterodera zeae* on maize. *Indian J. Nematol.* **15**: 18-20.

Srivastava, A. N. and Sethi, C. L. (1985b). Effect of temperature on larval emergence of *Heterodera zeae*. *Indian J. Nematol.* **15**: 242-243.

Srivastava, A. N. and Sethi, C. L. (1986a). Plant parasitic nematodes infesting maize and millets. *Indian Phytopath.* **39**: 160-161.

Srivastava, A. N. and Sethi, C. L. (1986b). Seasonal population fluctuations of *Heterodera zeae, Rotylenchulus reniformis* and *Tylenchorhynchus vulgaris* in maize- cowpea- wheat rotation. *Indian. J. Nematol.* **61**: 16-18.

Srivastava, A. N. and Sethi, C. L. (1987). Additional host records of *Heterodera sorghi*. *Indian J. Nematol.* **17**: 342-343.

Srivastava, A. N. and Sethi, C. L. (1989a). Effectiveness of nematicidal spray as a method to manage maize cyst nematode, *Heterodera zeae. Indian Phytopath.* **42**: 290.

Srivastava, A. N. and Sethi, C. L. (1989b). Seed treatment as a method in control of maize cyst nematode, *Heterodera zeae. Indian Phytopath.* **42**: 303..

Srivastava, A.N., Walia, R.K. and Hanuman Singh (1995). "Nematode Problems in maize." In: *Nematode Pest Management - An Appraisal of Eco-friendly Approaches* (Eds. Gopal Swarup, D.R. Dasgupta and J.S. Gill. Nematological Society of India. Pp 134-139.

Stradioto, M.F., Barbosa Ferraz, L.C.G. and Pitelli, R.A. (1983), Dinamica populacional de *Pratylenchus brachyurus* em cultura de Milho *(Zea mays* L.) infestada por plantas daninhas. *Soc. Brazil. Nemat. Public.* 7: 99-115.

Swarup, G., Prasad, S.K. and Raski, D.J. (1964). Some *Heterodera* species from India. *Plant Disease Reporter.* **48**: 235.

Upadhyay, K.D. Swarup, G. and Sethi, C.L. (1972a). *Tylenchorhynchus vulgaris* sp.n. associated with maize roots in India, with notes on its embryology and life history. *Indian J. Nematol.* **2**: 129-138.

Upadhyay, K.D. and Swarup. G. (1972b). Culturing, host range and factors affecting multiplication of *Tylenchorhychus vulgaris* on maize. *Indian J. Nematol.* **2**: 139-145.

Upadhyay, K.D. and Swarup, G. (1976). Reaction of some maize varieties against *Tylenchorhynchus vulgaris. Indian J. Nematol.* **6**: 105.

Upadhyay, K.D. and Swarup, G. (1981). Growth of maize plants in presence of *Tylenchorhynchus vulgaris* singly and in combination with *Pratylenchus zeae* and *Fusarium moniliforme. Indian J. Nematol.* **11**: 29-34.

Walia, R.K. (1982). Ph.D. thesis, Post Graduate School, Indian Agricultural Research Institute, New Delhi.

Walters, M.C. (1979). The possible status of parasitic nematodes as limiting factors in maize production in South Africa, proceedings second South Africa Maize Breeding Symposium, Pietermaritzburg, 1976. *Technical Service Republic of South Africa.* **142**: 112-118.

❑❑❑

7

Economic Management of Phyto-Nematodes in Pulse Crops

Dr. S.D. Mishra

Introduction

India is a major pulse growing country in the world. These crops occupy an important position in Indian agriculture and are the main source of vegetarian protein (17-43%) and supplement to the cereal-based diet in our country. Pulses are integral part of Indian diets for all sections of the society. Pulse crops are cultivated over an area of 23 million hectares with a total production of 14.8 million tonnes. The productivity of pulses is 536 kg./ha., which is very low when compared to that in other countries. Pulses occupy important position in rainfed farming system, generally grown in rainy (*kharif*) and post-rainy (*rabi*) seasons. The commonly grown pulse crops in this country are chickpea *(Cicer arietinum)*, pigeonpea *(Cajanus cajan)*, uradbean (*Vigna mungo*), mungbean (*Vigna radiata*), horsegram, mothbean (*Vigna aconitifolia*), khesari (*Lathyrus sativa),* lentil (*Lens esculentum*), kulthi (*Dolichus oliflorus*), rajmah (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*) and pea *(Pisum sativum)* (Jain, 1988). Summer pulses like greengram and blackgram are also grown under irrigated areas. Pigeonpea, greengram, blackgram, moth, and cowpea are mostly grown in rainy season. Pulses like chickpea, lentil and pea are grown during post-rainy season. The demand of pulses in India is more due to dietary habits. The per capita availability of pulses in India has declined with sharp increase in human population, resulting in under nutrition and malnutrition problems (Yadav, 1986). Pulses are important source of livelihoods of million of people, especially in the developing countries where, from their production, households derive food, animal feed and income. Also because of their ability to fix atmospheric nitrogen, they play a key role in maintaining soil fertility and ensuring sustainability of production systems, particularly in low-input, small-scale agriculture.

Like other agricultural crops pulses also suffer from several biotic (diseases, insect pests, parasitic nematodes and weeds etc.) and abiotic constraints of which pests

and diseases are the most important. The greatest challenge for pulse researchers is to reduce their susceptibility to host of these factors that prevent the full realisation of yield potential. Phytoparasitic (Plant parasitic) nematodes, the soil inhabiting pests are considered one of the major biotic constraints and limiting factors in the production of most of the pulses which are infested by a wide range of nematode pests and are highly vulnerable to them (Nene *et al.*, 1989) but the major nematode species belong to sedentary endo-parasitic group. In intensive cropping system, they often cause severe damage to most of the agricultural crops when present in mixed population. A number of plant parasitic nematode species from different genera like *Helicotylenchus, Hemicrico-nemoides, Heterodera, Hoplolaimus, Longidorous, Macroposthonia, Meloidogyne, Pratylenchus, Radopholus, Rotylenchulus, Scutellonema* and *Tylenchorhynchus* are reported to be associated with different pulse crops (Sharma, 1985; Gill and Singh, 1989) but major ones belong to three major endoparasitic nematodes of pulse crops *viz. Heterodera cajani, Meloidogyne incognita* and *Rotylenchulus reniformis* (Mishra, 1992) which are the vascular pathogen and distort the anatomical organisation of stele region. There would be higher metabolic activity in the infected roots which favours the accumulation of nutrients in the roots and thus causes the inability to supply them to the above ground plant parts (Das and Mishra, 1999).

Crop Losses

In general, they cause reduction in growth, rhizobial nodulation, plant nutrients, total root biomass, bulk density of stems, pollen fertility, water absorption capacity and finally yield reduction in most of the pulse crops may be in varying degree depending upon the level of nematode infestation. There are no reports on the nationwide economic losses caused by nematodes to pulses. However yield loss estimates in nematicidal trials have indicated 20-43% loss in yield of blackgram, frenchbean, greengram and pigeonpea due to pigeonpea cyst nematode (Reddy, 1985; Sharma *et al.*, 1992). *Heterodera cajani* has been reported to infect pigeonpea to such an extent that it may cause the loss of grain yield upto 30 per cent under field conditions (Saxena and Reddy, 1987). Root-knot, pigeonpea cyst, reniform and lance nematodes were found to be potential nematode pests of pigeonpea causing patchy growth, stunting and poor yields. These nematodes may cause yield losses upto 30 per cent, which may vary from 20 to 75 per cent depending upon the level of nematode infestation. In chickpea, *Meloidogyne incognita, Heterodera cajani, Pratylenchus thornei, Tylenchorhynchus brassicae* and *T. indicus* reproduced at very high rate and regarded as potential parasitic nematodes causing poor germination, uneven growth, stunting, galls on roots and low yield (Mishra *et al.*, 2005). The

economic damage caused by nematodes becomes highly aggravated in association with some micro-organisms such as the *Fusarium* spp. The damage caused by nematodes remained unrecognised for several years because of subterranean habit of the nematodes, subtle nature of damage and general lack of awareness of their presence in the plants.

Nematode Management

Although nematodes are reported to cause significant production losses in different parts of the world, it appears that practical nematode management options that farmers can easily afford and apply for achieving economic benefits have either not been communicated to the stakeholders or they have not been used due to lack of understanding of losses caused by the nematodes. Recent research has shown potential for the eco-friendly options *viz.* genetic improvement in crop cultivars, improved bio-control agents, use of botanicals such as neem and adoption of pest suppressing cultural practices. While the range of available eco-friendly nematode control options has been expanded, there is a need for fine-tuning of most of the technologies to match the resource base of farmers in the arid and semi-arid ecologies. Community participation models for building up farmers' awareness on Integrated Nematode Management (INM) should receive more emphasis. Combinations of seed treatments, summer ploughing, cropping systems, use of resistant cultivars and other physical and chemical control measures need to be stressed. Greater focus on inter-disciplinary research approach also could enhance the scope for INM.

Use of Nematicides

Option for the management of nematode pests of pulse crops by a combination of chemical and non-chemical methods have been developed but pulse growers in India are not conscious of the need to protect their crops from these organisms. Aldicarb, carbofuran and phenamiphos effectively reduce nematode population on many pulse crops. Seed treatment with these chemicals have shown good protection against cyst, root-knot and reniform nematodes. Seed treatment with 1-3 per cent carbofuran/ carbosulphan is effective against *Meloidogyne* spp. On cowpea, blackgram, pea, frenchbean, chickpea and pigeonpea. It is also effective against *Heterodera cajani* on pigeonpea. The traditional cultural practices such as crop rotation, summer ploughing and fallowing affect the incidence as well as severity of nematode damage. The productivity of pulse crops can be enhanced by adopting suitable measures of nematode management. Since, nematode management is yet to be perfected because most of the nematicides (synthetic chemicals) are not available in the market and majority of them are expensive

and also supposed to have residual effects in the soil, as high doses are required for restricting inhabiting nematodes, search for alternative methods particularly non-traditional nematicides or non-chemical methods are becoming the necessity of the time. The use of chemicals for the nematode management is either being discouraged these days or they are being used in the ways in which they are economical.

Seed treatment with biopesticides (neem seed powder @ 5% w/w; latex of *Calotropis procera* @ 1% w/w and neemark @ 5% w/w), chemicals (dimethoate @ 8 ml/kg seed; triazophos @ 1% w/w; chlorpyriphos @ 10 ml / kg seed and carbofuran @ 2 kg a.i. /ha) and bioagents (*Paecilomyces lilacinus* @ 10 ml /100 g seed; *Aspergillus niger* @ 200 g/kg seed and *Trichoderma viride* @ 200 g/kg seed) against plant parasitic nematodes associated with chickpea effectively controlled the root-knot nematode infestation as evidenced from the observations recorded at the harvest of the crop on population build up of nematodes, plant growth parameters and grain yield (Mishra *et al.*, 2003).

Soil Solarisation

Soil solarisation has been found very effective in minimising the soil population of plant parasitic nematodes. In this case, the soil surface is covered with transparent polythene sheet that traps solar heat. During summer season, 2-3 summer ploughings at fortnight interval provide significant reduction in the population of nematodes but the efficacy of summer ploughing is enhanced by polythene mulching that traps and retains solar heat for a longer duration. Polythene sheets used for solarisation are very expensive for resource poor farmers growing subsistence crops over relatively larger areas, but this technology has been adopted by commercial farmers, nurseries and gardeners growing small plots of high value cash crops such as tomatoes and other vegetables. The pigeonpea cyst nematode and reniform nematodes are effectively controlled by this method (Sharma and Nene, 1990).

Crop Rotation and Cropping Systems

The crop rotation is very useful option to suppress the population densities of nematode parasite of pulses. Generally the rotation of pulse crops with cereals for 2-3 years is generally effective in controlling the nematodes (Sharma *et al.*, 1996). Intercropping of sorghum or bajra with pigeonpea improves the productivity and reduction in the population of pigeonpea cyst nematodes (Mishra *et al.*, 2005). Mohanty and Phukan (1990) studied the effect of crop rotations on the development of *Meloidogyne incognita* on black gram including crop sequences as black gram, mustard,

rice, black gram followed by the sequence black gram, fodder cowpea, rice. This rotation was found to be effective in reducing galls or egg masses on the roots of black gram.

The cropping systems followed in respect of different crops also play important role in the infestation of nematodes. The cropping systems of pigeonpea + bajra-fallow or inter-cropping with sorghum/sesamum at 1:1 ratio was found promising in reducing pigeonpea cyst and root-knot nematodes population in field. Short duration pigeonpea followed by cereals or fallow may be an effective method to keep the nematode population down. Nematode infestation may be minimised by inter-cropping of maize + pigeonpea and sorghum + pigeonpea in comparison with growing sole crop of pigeonpea. Similarly inter-cropping of mustard with chickpea may be an effective method of reducing nematode population. In mustard + chickpea inter-cropping systems, infestation of root-knot nematode was less than sole crop of chickpea (Mishra *et al.*, 2005).

Resistant Varieties

Growing resistant varieties against nematodes is an ideal method for nematode management. This approach is useful for low value cash crops. There are many crop cultivars reported to be resistant to the attack of plant parasitic nematodes infecting pulse crops. Many good sources of resistance to nematodes have been identified which need to be incorporated in breeding programmes. Many new techniques *viz.* micro-propagation, anther culture, embryo rescue, somaclonal variation, somatic hybridisation and transformation can make the process of transfer of resistance genes easy and precise. The wild relatives of pigeonpea have several useful genes for resistance to *H. cajani, R. reniformis* and *M. incognita*. The time has come to exploit new molecular techniques to enhance resistance breeding programmes.

Soil Amendments

Various organic materials *viz.* oil cakes of neem (*Azadirachta indica*), linseed (*Linum usitatissimum*), mustard (*Brassica rapa*), mahua *(Madhuca indica*), karanj (*Pongamia glabra*) and sawdust reduce root-knot nematode population, increase soil fertility and also improve soil structure. Addition of neem cake becomes more effective as compared to cakes of karanj and mustard in controlling nematode population (Yadav and Alam, 1992). The decomposed neem seed is also useful in reducing root-knot nematode population and enhancing the plant growth. Such amendments also have residual effect both in respect of soil fertility as well as in respect of their nematicidal value.

Biological Control

A large number of bio-agents have been identified having nematicidal value. Fungi like *Paecilomyces lilacinus* and bacterium like *Pasteuria penetrans* have shown their potential against ***H. cajani*** and *M. incognita* (Sharma and Swarup, 1988). This approach has some limitations *viz.* bulk production, storage and requirement of bioagents for large scale production in the field. A great deal of research effort is desired to overcome these limitations. It is also difficult to modify the soil environment for long periods. The use of bioagents is presently feasible for nursery bed treatment or for treatment of seed.

Nematode Management through Neem Products

Nematicidal nature of various parts and products of neem have been extensively exploited on their direct toxicity, soil application and seed treatment in the management of nematode pests and reviewed by various workers (Mojumder and Mishra, 1993; Mojumder, 1995). Neem is a rich source of bioactive organic chemicals comprising of repellent, feeding deterrents, toxicants, antifeedants etc. had been widely tested for its nematicidal value too. All parts (leaf, flower, bark, gum, root, fruit, seed, seed kernel and seed coat) have nematicidal potential (Mojumder and Mishra, 1993). Neem products are most widely used for generations in India with broad spectrum pesticidal value both for pest management as well as for increasing soil fertility. There are a number of neem based commercial formulations available in the market commercially, some of which have been tested against nematodes and shown nematicidal value. The cost of neem products for nematode management could effectively be reduced by using them as seed dressing and seed coating.

Some effective and adoptable nematode management strategies encorporating neem and other materials are given below:

(a) The use of neem seed powder and neem based formulations *viz.* Achook, neemark, neemgold, nimbecidine and fieldmarshal as seed soaking @ 5 and 10% against *Meloidogyne incognita, Heterodera cajani* and *Rotylenchulus reniformis* was found to be an efficient method to reduce the nematode population in soil and to improve the plant growth of pigeonpea (Das and Mishra, 2000).

(b) Neem seed powder as seed treatment @ 10% w/w and as soil application @ 50 kg/ha, soil solarisation (transparent polythene sheets of 400 gauge thickness for a period of four weeks) and VAM @ 100 kg/ha provided good plant growth and

yield of pigeonpea by effectively controlling the detrimental effects of *Heterodera cajani*. Maximum reduction in nematode population was observed in the integrated management schedules adopted as: (i) Soil solarisation + soil application of neem seed powder + VAM, and (ii) Soil solarisation + seed treatment with neem seed powder + VAM (Nageswari and Mishra, 2005). The cost benefit ratio calculated for these treatments revealed that they were economically viable too as it was 1: 2.54 and 1: 2.60 in case of treatments (i) and (ii), respectively.

(c) Seed treatment with neem seed powder, neemgold and nimbecidine @ 10% w/w were found effective in providing better plant growth in pigeonpea and significant reduction in the infestation of *Heterodera cajani* (Das and Mishra, 2000).

(d) Seed treatment with neem seed powder @ 5% w/w in combination with latex of *Calotropis procera* @ 1% v/w reduced the nematode population as well as wilting of plants to a considerable extent and increased the yield of pigeonpea varieties UPAS-120 and Bahar by above two fold and by 35%, respectively (Mishra *et al.*, 2005).

(e) Highest economic returns could be achieved with integrated approach against nematodes infesting pigeonpea *viz.* (i) seed treatment with neem seed powder @ 5% w/w + latex of *Calotropis procera* @ 1% v/w and intercropping with bajra, (ii) soil application of neem seed powder @ 50 kg/ha and summer ploughing 2-3 times at fortnight interval (Mishra *et al.*, 2005).

(f) Soil application of neem seed powder @ 50 kg/ha and its seed treatment @ 5% w/w increased the grain yield of chickpea by more than 30% over check and reduced the nematode population upto 40% (Mishra *et al.*, 2005).

(g) Seed treatment with neem seed powder @ 5% w/w + latex of *Calotropis procera* @ 1% v/w against root-knot nematode and wilt complex in chickpea proved to be an effective approach (Mishra *et al.*, 2005).

(h) Seed treatment with neem seed powder @ 5% w/w and spore suspension of *Trichoderma harzianum* @ 2% v/w reduced the nematode infestation and wilting of chickpea plants and increased the grain yield by two fold (Mishra *et al.*, 2005).

(i) Combined application of neem products (neem seed powder, neemgold, and nimbecidine @ 50 kg/ha) and carbofuran @ 1 kg/ha showed better compatibility

than phorate @ 1 kg/ha and could be a better option for integrated management schedule against root-knot nematode menace in chickpea (Chakrabarti and Mishra, 2000).

(j) Seed treatment with neem seed powder @ 10% w/w along with soil application of carbofuran @ 1 kg a.i./ha could be the best option for the subsistence level of chickpea growing in India. The split-dose of soil application of neem seed powder (50 + 50 kg/ha), though a costly input, increase the efficiency of carbofuran by 9.2% than when applied alone and hence increase the benefit-cost ratio to 1.65. Moreover, this management package may save the protein and starch quantity of chickpea grains in the infected grains (Chakrabarti and Mishra, 2001).

(k) Soil application of neem seed powder, neemgold and neemark @ 50 kg/ha provided significant reduction in the population of *Meloidogyne incognita, Heterodera cajani* and *Rotylenchulus reniformis* (Das and Mishra, 2003).

(l) Combined application of neem seed powder as seed treatment @ 5% w/w and chemicals (carbofuran/phorate @ 0.75 kg/ha) provided good reduction in the population of *Heterodera avenae* infesting wheat (Pankaj *et al.*, 2003).

(m) Integration of different management practices is considered as better option to an individual approach. Integration of soil solarisation (for six weeks), Vasicular arbuscular mycorrhiza fungus (VAM), *Glomus fasciculatum* inoculation and seed treatment with carbosulfan (@ 3% w/w) is highly effective in reducing population of *M. incognita* and *Fusarium oxysporum* and significantly increasing chickpea grain yield (Rao and Krishnappa, 1995). Seed treatment with carbendazim (0.25% w/w) together with carbosulfan (3% w/w) is effective in reducing the Fusarium-Meloidogyne wilt complex and increasing the yields.

Conclusion

Plant parasitic nematodes are the hidden enemies of farmers which cause severe damage to our most of the agricultural crops including pulses. These tiny micro-organisms are microscopic hence cannot be seen with naked eyes. Being extensive in occurrence, they cause greater crop damage in favourable soil conditions and continuous susceptible crops one after the other. The lack of awareness about these pests may be one of the main reasons of the damage. As the farmers have little perception of nematodes due to their microscopic size and subterranean habitat, the damage to crop productivity

continues unchecked. The need for development of programmes to educate farmers about nematode problems and to develop inexpensive, environmentally safe and effective management of the nematode diseases are very essential to protect the crops due to huge damage. There is urgent need of suitable recommendations for nematode management practices being practical, reliable, sustainable in the long-term and adaptable to different farming systems and farmers.

References

Chakrabarti, U. and Mishra, S.D. (2000). Integrated management of root-knot nematodes in chickpea through soil application of neem products and systemic nematicides. *Journal of farming systems Research and Development*, **6**: (1&2): 79-83.

Chakrabarti, U. and Mishra, S.D. (2001). Seed treatments with neem products for Integrated management of *Meloidogyne incognita* infecting chickpea. *Current Nematol.* **12** (1, 2): 15-19.

Das, Dibakar and Mishra, S.D. (1999). Effect of different inoculum levels of *Meloidogyne incognita, Heterodera cajani* and *Rotylenchulus reniformis* alone and in combinations on their population development and growth of pigeonpea. *Current Nematol.,* **10** (1,2): 55-62.

Das, Dibakar and Mishra, S.D. (2000). Effect of neem seed powder and neem based formulations as seed coating against *Meloidogyne incognita, Heterodera cajani* and *Rotylenchulus reniformis* infecting pigeonpea. *Current Nematol.,* **11** (1,2): 13-23.

Das, Dibakar and Mishra, S.D. (2003). Effect of neem seed powder and neem based formulations for the management of *Meloidogyne incognita, Heterodera cajani* and *Rotylenchulus reniformis* infecting pigeonpea. *Ann. Pl. Protec. Sci.* **11** (1): 110-115.

Gill, J.S. and Singh, R.V. (1989). In: *Progress in Plant Nematology.* (Eds., Saxena, S.K., Khan, Khan, A.N., Rashid, A., and Khan, R.M.) pp. 5-3-514, CBS Publishers and Distributors Pvt. Ltd., India.

Jain, H.K. (1988). In: *Pulse Crops* (Eds., Baldev, B., Ramanujam, S., and Jain, H.K.) pp. 52-91. Oxford and IBH Co., New Delhi.

Mishra, S.D. (1992). "Nematode pests of pulse crops." In.: *Nematode Pests of Crops.* (Eds. Bhati, D. S., and Walia, R.K.), pp. 139-148. CAB Publishers and distributors Pvt. Ltd. India.

Mishra, S.D. and Prasad, S. K. (1974). Effect of soil amendments on nematodes and crop yields. I. Oil seed cakes, organic matter, inorganic fertilizers and growth regulators on nematodes associated with wheat and their residual effect on mung. *Indian J. Nematol.* **4** (1): 1-19.

Mishra, S.D., Dhawan, S.C., Tripathi, M.N. and Saswati Nayak (2003). Field evaluation of Biopesticides, chemicals and Bioagents on plant parasitic nematodes infesting chickpea. *Current Nematol.* **14** (1,2): 89-92.

Mishra, S.D., Dhawan, S.C., Ali, S.S., Haseeb, A. and Lingaraju, S. (2005). "Integrated management of plant nematodes/soil pathogens in pulses based cropping systems." *Final Report NATP (RPPS-2)*: pp. 1-61.

Mojumder, V. and Mishra, S.D. (1993). "Management of nematode pest." In: *Neem in Agriculture. IARI, Res. Bull. No.* 4 (Eds. B.S. Parmar and R.P. Singh), pp. 40-48.

Mojumder, V. (1995). "Nematoda, Nematodes." *The neem tree, a source of unique products of pest management and other purpose* (Eds. H. Schmutterer), pp. 120-150. UCH postfach, Weinheim, Germany.

Nageswari, S. and Mishra, S.D. (2005). Integrated nematode management schedule incorporating neem products, VAM and soil solarisation against *Heterodera cajani* infecting pigeonpea. *Indian J. Nematol.* **35** (1): 68-71.

Nageswari, S. and Mishra, S.D. (2005). Neem formulations as seed treatment against *Heterodera cajani* infecting pigeonpea. *Ann.Pl. Protec. Sci.* **13** (20): 515-516.

Nene, Y.L., Sheila, V.K. and Sharma, S.B. (1989). A world list of chickpea and pigeonpea pathogens. *Legumes pathology progress report No. 7. Patancheru, A.P., ICRISAT,* India, pp.23.

Reddy, P.P. (1985). Estimation of crop losses in peas due to *Meloidogyne incognita. Indian J. Nematol.* **15**: 226.

Saxena, R. and Reddy, D.D.R. (1987). Crop lossesin pigeonpea and mungbean by pigeonpea cyst nematode, *Heterodera cajani. Indian J. Nematol.* **17**: 91-94.

Sharma, S. B. (1985). "Nematode diseases of chickpea and pigeonpea." *Pulse Pathology Progress Report-43.* Patancheru, A. P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics, 103pp.

Sharma, S. B. (1995). *ICRISAT Pulse Pathol. Prog. Report. 42*, A.P., India.

Sharma, S. B., Rego, T. J., Mohiuddin, M., and Rao, V. N. (1996). Regulation of population densities of *Heterodera cajani* and other plant parasitic nematodes by crop rotation on Vertisols in semi-arid tropical production systems in India. *J. of Nematology*, **28**: 244-51.

Sharma, S. B, and Nene, Y. L. (1990). Effects of soil solarisation on nematodes parasitic to chickpea and pigeonpea. Supplement of *Journal of Nematology*, **22**: 658-64.

Sharma, R., and Swarup, G. (1988). *Pathology of cyst nematodes.* Malhotra Publishing House, New Delhi, India. 88 pp.

Sharma, S. B., Smith, D.H. and Mc Donald, D. (1992). Nematode constraints in chickpea and pigeonpea production in semi-arid tropics. *Plant Disease*, **76**: 868-874.

Yadav, B.S. (1986). "Nematode problems of pulse crops." In: *Plant-parasitic nematodes of India: Problems and Progress*, IARI, New Delhi, pp. 328-335.

❑❑❑

8

Plant Parasitic Nematodes: A Limiting Factor to the Cultivation of Medicinal and Aromatic Plants and their Management Strategies

Akhtar Haseeb and Anita Sharma

" There is nothing in this universe, which is non-medicinal, which cannot be made use for many purposes and by many modes." ***-Ashtaanga Hrdaya*, "Sutra Sthana"**

Introduction

Plants have been a major source of therapeutic agents for alleviation or cure of human diseases since time immemorial. These are extensively utilised throughout the world in both the two distinct areas of health management, *i.e.*, (i) Modern system of medicine system, and (ii) Traditional system of medicine. When we talk of India with regard to medicinal plants, we are a huge treasure house! As a group, medicinal plants comprise approximately 8,000 sp. and account for around 50 per cent of all the higher flowering plant species of India. The Indian systems of medicine have identified around 1,500 medicinal plants, of which 500 species are mostly used in the preparation of drugs. The importance of these medicinal plants can be judged from the fact that more than 90 per cent drugs used in the traditional and folk system of medicine in most of the tropical countries of the world come from these plants.

Though, these plants have been known and used since ancient times to heal and cure diseases, recently, technological advancements and validation of traditional knowledge and usage are leading to consumer inclination towards naturals and high market and value for these crops. Such crops in India now covering an area of mearly about 0.4 million hactare are finding a much higher place in international agri-business with an estimated annual growth rate of 10-15 per cent.

In view of the tremendous demands of the plants throughout the world in medicine, phytochemicals, neutraceuticals, cosmetic and other products, they have become a major sector of trade and commerce.

Today, various medicinal and aromatic plants are cultivated by large number of farmers throughout the country as non-conventional crops. With the development of superior varieties and improved agronomic practices for augmenting per unit area field of medicinal and aromatic crops, due attention was also paid towards various nematode diseases and their control.

Mentha Species (Mint)

Mints have been known from the time immemorial as kitchen herbs and also as the pharmacopoeial herbs of the ancient human civilisation. Mints belong to family Lamiaceae and genus *Mentha*. Four species of mints that are commonly cultivated in India include menthol mint (*Mentha arvensis* L. subsp. *haplocalyx* Briquet var. *piperascens* Holmes), Bergamot mint (*M. citrata* Ehrh), Peppermint (*M. piperita* L.), spearmint (*M. spicata* L.). The oil of these mints and their active constituents has great demand in flavouring, perfumery, cosmetic and pharmaceutical industries. Among them, menthol mint (*M. arvensis*) is the most important crop grown on commercial scale in several parts of the world. In India it has become the prime essential oil bearing crop due to remunerative prices of its products and suitability to adjust in the existing cropping system, without disturbing the main cereal crops.

Root-knot Nematodes (*Meloidogyne* species)

In 1938, Buhrer for the first time reported, *M. arvensis* and *M. piperita* as hosts of *Meloidogyne* species. Horner and Jensen (1954) reported high population of *M. hapla* chitwood, 1949 in different mints in western Oregan, they have also established the pathogenicity of *M. hapla* on scotch spearmint, *M. cardiaca*. In India also larvae of *Meloidogyne* spp. were found present in the rhizosphere soil of *M. spicata* (Haseeb, 1992-94; Haseeb and Shukla, 2000a). Skotland and Menzies (1957) reported *M. hapla* as most prevalent species associated with *M. piperita* cv. Mitcham in Yakima valley and the Columbia basin. Later, Maqbool *et al.* (1985) also reported severe galling of *M. piperita* due to infestation of *M. hapla.*

The main symptom of the disease in field conditions is occasional yellowing of leaves, stunting and wilting of plants. In general, leaves become yellow and thin, scorch easily and eventually turn brown. Initially, symptoms of the disease appears in patches as the reduced plant growth with smaller leaf size and temporary wilting under slightest

stress of water. As the crop grows especially after first harvest, symptoms become more severe with yellowing of leaves, while veins remain green. Whereas, the below ground symptoms are the galls of various sizes with large egg masses on the root system (Haseeb and Shukla, 2000a, 2001).

For the first time Anonymous (1984, 1985, 1986, 1987a) and Haseeb and Pandey (1989b) reported, root-knot disease of Japanese mint and Bergamot mint, root-knot species attacking to different cultivars and species of mints were identified as *M. incognita* and *M. javanica*, generally mixed infection of *M. incognita* and *M. javanica* were found on the same root system. However, variation in the percentage occurrence of individual species of root-knot nematode varies with the cultivars of mint.

Anonymous (1984, 1985, 1986) and Haseeb and Shukla (2000a, 2001) studied the population fluctuation of larvae of root-knot nematodes in the rhizosphere of different mints in relation to seasonal changes. Population of root-knot larvae in soil fluctuates greatly from season to season and cultivars to cultivars. The highest number of nematodes was found around the rhizosphere of *M. arvensis* whereas lowest number was found on *M. citrata*.

Pathogenic potential of *M. incognita* on different cultivars of *M. arvensis* was determined. An increase in initial number of nematodes/pot resulted in increased reduction in plant fresh and dry weights, leaf chlorophyll content, photosynthetic efficiency of leaves and essential oil content in fresh herb (Anonymous, 1986, 1987a; Pandey *et al.*, 1992; Haseeb and Shukla, 2000a). Consistent presence of *Meloidogyne* spp. in the rhizosphere of *M. piperita* cvs. MP-1 and MPS-1 has been reported in experimental beds of CIMAP, Lucknow (Haseeb, 1992-94). Among various cultivars of *M. arvensis* tested, MAS-1 and HY-77 were found highly susceptible, while Shivalik, Gomti, Kosi and Himalaya showed slight tolerance to the infection by *M. incognita*. Reproduction of *M. incognita* and extent of galling on roots and suckers were observed directly proportional to susceptibility of cultivars of *Mentha* (Haseeb and Shukla, 2000a, 2001).

Haseeb and Shukla (2000a, 2001) also studied the effect of pH, soil type on the growth/oil yield of *M. arvensis* and reproduction of *M. incognita*. Results indicated a directly proportional relation between pH level and severity of disease. High clay and organic matter was observed to support the nematodes and enhanced the growth and yield.

The severity of root-knot disease of Japanese mint was increased under field conditions in the presence of soil-borne fungi, particularly the species of *Fusarium* and

Rhizoctonia. Studies conducted under controlled conditions indicated that *M. incognita* – *Sclerotinia sclerotiorum* disease complex caused severe reduction in growth and oil yield (Haseeb and Sharma, 2005).

Root Lesion Nematode (*Pratylenchus* sp.)

The genus *Pratylenchus* was established by Filipjev in 1936 and more than 50 species are known today. It is the next potential pest after the root-knot nematodes. The symptoms on the aerial portion caused by *Pratylenchus* sp. are stunting and wilting like that of root-knot nematodes. However, on roots and suckers it causes specific symptom in the form of light brown to dark coloured lesions. In severe cases whole underground portion becomes black and rotting of cortical portion takes place, first due to the nematode infection and later because of the invasion of other pathogens or saprophytic attack on necrotic cells (Anonymous, 1984-1987a; Haseeb, 1992-94). Skotland and Menzies (1957) for the first time reported the association of *P. minyus*, *P. thornei* and *P. penetrans* with *M. cardiaca* var. Scotch, *M. piperita* Var. Mitcham and *M. spicata* var. Native from the Yakima valley. *P. thornei* has been considered as the most dominant nematode of *M. citrata* (Haseeb, 1992, 1993, 1994; Haseeb and Shukla, 1995). Pathogenicity experiment of *P. penetrans* on *M. spicata* and *M. piperita* showed a reduction in foliage and root/stolon growth up to 34% and 66% respectively as reported for the first time by Bergeson in 1963. The population of *P. penetrans* increased ranging from 30x to 80x after 8 months. Bergeson and Green (1979), further reported that the *P. penetrans* was mainly responsible in the reduction in herb weight and root growth of spearmint and peppermint in Indiana. Subsequently they have proved that all the test cultivars of peppermint grown in Indiana were equally susceptible to *P. penetrans*. According to Rhoades (1983) *P. scribneri* was found to be responsible in stunting of spearmint grown in Sherbak off and Stanelly in Central Florida. He also established the pathogenicity of *P. scribneri* on *M. spicata* in glass house conditions. Stunting and chlorosis of plants and reduction in clipping weight of *M. spicata* was obtained within 4-5 months of inoculation with the nematodes. Pinkerton (1984) in greenhouse studies reported that *P. penetrans* significantly reduced crop yield of *M. spicata*. In the experiment he found that *M. spicata* cv. Murroy Mitchem is highly susceptible while cultivar Todd Mitchem was intermediate and Black mitchem was the most tolerant cultivars to *P. penetrans*.

Haseeb and Shukla (1994b, 1996, 2000b) established the pathogenicity of *P. thornei* on *M. arvensis* cv. HY77, *M. piperita* cv. MPS-1 and *M. spicata* cv. MSS-5 and reported that significant reduction in plant fresh and dry weight, chlorophyll, sugar,

phenol and oil content started at inoculum level of 250 nematodes/7.5 kg soil. They also reported, suppressed reproduction factor of both *P. thornei* and *M. incognita*, when present simultaneously on *M. arvensis*. Studies regarding the effect of soil pH on *P. thornei* infesting *M. piperita* indicated that the highest reproduction of nematodes was observed at pH 6.0 followed by 9.0 and 3.0 respectively (Shukla *et al.*, 1998b). Similar studies regarding the effect of soil texture and its organic matter content indicated that soil type may also play a very important role on the activities of *P. thornei* in the rhizosphere of *M. piperita* (Shukla *et al.*, 1998a). Seasonal changes such as temperature and rainfall have been considered important to influence the losses to mints due to *Pratylenchus* sp. (Haseeb and Shukla, 1994a).

It has been reported that *Pratylenchus* also plays a significant role on the increase in severity of other soil-borne pathogens (Haseeb and Shukla, 2000a, 2001). Bergeson (1963) for the first time determined the effect of *P. penetrans* alone and in combination with *V. albo-atrum* on peppermint. *P. penetrans* alone significantly reduced the foliage and root weight. However, the diagnostic symptoms of *Verticillium* wilt appeared 2-3 weeks earlier in plants inoculated with *P. penetrans* and *V. albo-atrum* than in plants inoculated with *V. albo-atrum* alone. Faulkner and Scotland (1963) reported that the *P. minyus* has been found throughout the Yakima valley of Washington, U.S.A. in association with *V. dahliae* (Kleb) *f. menthae*. Later, Faulkner and Skotland (1965) reported that the *P. minyus* increased in both the incidence and severity of *Verticillium* wilt of Peppermint. The duration for the appearance of disease syndrome was reduced 2-3 weeks by the presence of nematode. The reproduction rate of nematode was increased in plants inoculated with nematodes and fungus simultaneously than in plants inoculated with nematode alone.

Faulkner and Bolander (1969) have determined the influence of *P. minyus* and *V. dahliae* f. sp. *menthae* in the severity of wilt disease of peppermint at 18, 21, 24, 27 and 30°C soil temperature. Symptom expression was greatest at 27°C in plants inoculated with the nematode and fungus simultaneously. Whereas, at 24°C soil temperature, the disease symptom was most severe in plants inoculated with fungus alone. The highest population of *P. minyus* was recorded in plants inoculated with nematode and fungus simultaneously at a soil temperature of 24°C. whereas, the highest population of nematode was found at 30°C in plants inoculated with nematode alone.

Other Nematodes

In general plant parasitic nematodes other than *M. incognita* and *P. thornei* associated with mints do not produce characteristic symptom. Goodey (1940) reported

the association of *Aphelencoides olesistus* and *A. ritzembosi* with *M. piperita* and *M. spicata*. Horner and Jensen (1954) reported that *A. parietinus* and *Aphelencoides* sp. were recovered from the meristematic tissues of the emerging shoots of *M. piperita*. They further reported that as many as 4000 specimens of nematodes were found in a single shoot tips. Skotland and Menzies (1957) reported the association of *Tylenchorhynchus capitatus*, *Trichodorus* sp. with *M. cardiaca* var. Native in the Yakima valley and in Columbia basin. The commercial peppermint crop grown in Western Oregan, U.S.A. were severely infested with *Pratylenchus macrocephallus*. Rhizospheric soils of stunted and chlorotic plants containing more than 8000 *P. macrocephallus* per quart soil. However, all the developmental stages of the nematode was also isolated from the living stems and underground sprouting buds (Horner and Jensen, 1954). They also observed the reduced root system and rotting of roots in heavily infested plants.

Skotland and Menzies (1957) reported that *P. hamatus* was also associated with *M. cardiaca* var. Scotch, *M. piperita* var. Mitcham and *M. spicata* var. Native in the Yakima valley and in Columbia basin. In Washington, *P. hamatus* is a potential nematode causing serious damage to peppermint, Scotch and Native spearmint. The main expression of symptoms of diseased plants in the dwarfing of plants. Soil samples from rhizosphere of such plants often yielded 3,000-10,000 nematodes per unit soil and sometimes over, 4,00,000 nematodes may also be recovered as reported by Faulkner (1962). Later, Faulkner in 1964 reported that the fresh and dry weight of spearmint and peppermint were reduced 10-20% and 20-36%, respectively due to nematode inoculation. Delay in flowering of plants was also observed in inoculated plants. He also reported that the nematode population in soil was increased slowly during early weeks of the experiments, then quickly until plants started to produce flowers.

The *Longidorus elongatus* is the most prevalent nematode in flood plain along the Santiam and Willametle rivers of Western Oregan, U.S.A. affecting peppermint cultivation (Horner and Jensen, 1954). Usually, the infected plants were stunted and reddish in colour. The root system of such plants were poorly developed with most of feeder roots reduced to short stubby remnants. Also in heavily infected plant, roots look like a small tuft of cotton.

Rhoades (1983) reported that the severely stunted beds of *M. spicata* in Sherbakoff and Stanley in Central Florida, U.S.A. were found to be heavily infested with sting (*Belonolaimus longicaudatus*), awl (*Dolichodorus heterocephalus*), lesion (*Pratylenchus scribneri*) and stubby root (*Paratrichodorus christiei*) nematodes. In glass house experiments, all the species of nematodes were reproduced well on *M. spicata*. As

a result of inoculation with 500 and 2500 *P. longicaudatus*, *D. heterocephalus* and *P. scribneri* separately resulted in stunting, chlorosis and decreased 30, 46 and 52%, respectively in clipping weights of *M. spicata* within 4-5 months of inoculation. Root systems were also significantly reduced in weight. Inserra and Rhoades (1989) described the symptoms and the damage caused by *B. longicaudatus*, *D. heterocephalus*, *P. scribneri* and *Paratrichodorus christiei* separately on *M. spicata*. They have also suggested the use of non-volatile nematicides most effective for lowering nematode population and increasing yield.

Esmenjaud *et al.* (1990) found that three peppermint cultivars proved to be good host of *Pratelenchoides laticauda*. They further reported significant damage with this nematode species in USSR. Haseeb and Shukla (2000a, 2001) found that *Rotylenchulus reniformis*, *Helicotylenchus indicus*, *Tylenchorhynchus vulgaris*, *Hoplolaimus indicus* and *Paratylenchus* sp. reproduce well on mints and caused significant reduction in herb and oil yield.

Studies regarding the vertical distribution of plant parasitic nematodes associated with mints in relation to seasonal fluctuation indicated that *Tylenchus* sp., *T. vulgaris*, *Hoplolaimus indicus*, *Helicotylenchus indicus* were found throughout the year and *R. reniformis*, *Paratylenchus* sp., *Crionemoides* sp., *Hirschmaniella* sp., *Xiphinema* sp. and *Longidorus* pisi, etc., were found occasionally (Haseeb, 1992, 1993, 1994; Haseeb and Shukla, 2000a, 2001).

Management Studies

Jensen and Horner in 1956 established the pathogenicity of *L. elongatus* and controlled the disease by the application of soil fumigants. Jatala and Jensen (1974) controlled the *L. elongatus* infesting peppermint by using oxamyl as foliar applications. Such experiments were effective only when oxamyl was applied before, during and after exposure to nematodes. Pinkerton and Jensen (1983) reported that the treatment of oxamyl as spray and combined with aldicarb and oxamyl in soil as drench, resulted significant increase in the yield of oil and hay in first year after the application. The most effective treatments were the two broadcast spray or one granular incorporation of oxamyl. Maximum yield was obtained when the treatment was done in the month of November or March. Nematode population was only slightly and temporarily reduced however, did not correlate with yield response. Rhoades (1984) have studied the effect of carbofuran, fenamiphos and oxamyl @ 5.6 and 11.2 kg/ha and terbufos @ 11.2 kg/ha for the control of *P. scribneri* infesting *M. spicata*. The population of nematode was significantly reduced by all the test nematicides, while fenamiphos being the most

effective treatment, followed by terbufos. Both the rates of carbofuran and oxamyl were less effective in increasing the herb yield than the fenamiphos and terbufos treatments. Pinkerton *et al.* (1988) reported reduction in the population of *P. penetrans* and increase in herb yield of peppermint in treatments of oxamyl, aldicarb and carbofuran when they are applied as broadcast sprays during spring. Single treatment of 5.5 kg and 9.2 kg/ha in early April was as effective as multiple applications in April through June. Full applications of oxamyl and carbofuran neither reduced the multiplication of nematodes nor enhanced the spring growth.

Ingham *et al.* (1988) controlled the *P. penetrans* and *Paratylenchus* species on peppermint by using Vydate 2E (oxamyl) @ 1lb/acre, Mocap 6E or 10G (Ethophos) @ 3 to 6 lb/acre. They found that ethophos @ 6 lb/acre was highly effective in reducing population of *P. penetrans* both in soil and root tissues. However, oxamyl was useful for the reducing population of *Paratylenchus* species. Shukla and Haseeb (1996) managed *P. thornei* infesting *M. citrata*, *M. piperita* and *M. spicata* by the application of neem, mustard and linseed cakes @ 1500 kg/ha and aldicarb, carbofuran and ethoprop @ 4 kg a.i./ha under glass house conditions. Results indicated that neem cake was the most effective in improving the growth and oil yield and in reducing final nematode population in roots and soil followed by mustard cake, aldicarb, ethoprop, carbofuran and linseed cake respectively.

Haseeb and Shukla (2000a, 2001) conducted experiments under glasshouse and field conditions to manage root-knot nematodes infecting *M. arvensis* and *M. cardiaca*. The best results were achieved when soil was treated with neem cake and carbofuran. Results also indicated that application of hydro-distillation wastes of *M. arvensis*, *M. piperita*, *Cymbopogon martini* (Palmarosa), *C. winterianus* (Citronella) etc. in the soil (1 month after transplantation) was although found effective to reduce nematode population but enhanced termite attack. Successful control of *M. incognita* on *M. arvensis* was done by Haseeb *et al.*, (2005). Results showed that carbofuran was most effective followed by neem seed powder, neem cake, *T. harzianum*, *T. virens*, *P. fluorescens* respectively in increasing the plant growth and oil yield as well as in suppression of *M. incognita* reproduction and root-knot index.

Hot water treatment (40°C for 30 min) for complete eradication of *M. incognita* from *M. arvensis* planting material was suggested by Gokte and Mathur (1990). Haseeb and Shukla (2000a, 2001) suggested overnight soaking of suckers into 0.03% a.i. carbofuran for the eradication of *M. incognita* from the suckers.

Artemissia Pallens (Davana)

Davana (*Artemissia pallens* Wall.) is being cultivated in large scale in the USA, Europe and Japan for its high quality of essential oil. In India, it is being cultivated in the states of Andhra Pradesh, Tamil Nadu and Kerala. The annual production of davana oil in the country is about 1-2 tonnes. The main components of oil are cadinene, cinnamate, cinnamoyl, fenchyl alcohol, 10-11 phenols or acids, linalool, eugenol, geraniol and several sesquiterpenes.

Root-knot Nematodes (*Meloidogyne* Species)

Association of plant parasitic nematodes with Davana (*Artemissia pallens*) for the first time reported by Haseeb *et al.* (1986b). Later, Haseeb and Pandey (1989c) reported root-knot nematodes (*Meloidogyne* species) as the main problem in the cultivation of davana. The main disease symptom was the stunted growth of plants, less numbers of flowers/flower buds showing scanty appearance of the crop in fields. Various sizes of galls were found on root system of diseased plants. Haseeb and Pandey (1989c) established for the first time the pathogenicity of *M. incognita* on *A. pallens*. They reported that 1 larvae of *M. incognita*/ 2g soil as the economic threshold level for this crop; they further reported 52% reduction in oil yield of Davana at the highest inoculum level of *M. incognita*. An increase in initial inoculum density (=Pi) of the nematode resulted in corresponding decrease in fresh and dry plant weight and oil yield. Highest development of root-knot was observed in plants inoculated with 15,000 second stage juveniles. In general, an increase in initial inoculum densities of the nematodes resulted in corresponding decrease in nematode multiplication.

Management Studies

Haseeb and Butool (1991) determined the effect of aldicarb (4 kg a.i./ha), bavistin (4 kg a.i./ha), carbofuran (4 kg a.i./ha), mocap (6g kg a.i./ha), oncol (4 kg a.i./ha), rughby (4 kg a.i./ha) and, neem cake (@ 1g N/kg) on the control of *M. incognita* infesting davana. Various treatments brought out a significant increase in fresh and dry weight of plants/oil yield. The best result was obtained in plants treated with aldicarb followed by mocap, neem cake, carbofuran, rughby, bavistin and oncol respectively. Treatments with pesticides and oil-cake suppressed the nematode population in root and soil significantly and also decreased the root-knot index. Pandey (1994) in field experiment found maximum increase in root and shoot length, fresh and dry weight as well as the oil yield of davana plants when treated with neem cake followed by aldicarb (0.002 g a.i./kg), carbofuran (0.0015 g a.i./kg) and castor cake (@ 1g N/kg).

Hyoscyamus Species (Henbane)

Henbane (*Hyoscyamus* species Fam., Solanaceae) is an important medicinal herb containing one of the most valuable sources of tropane alkaloids, particularly hyoscyamine, hyoscine and atropine. The hyoscine and its derivatives have been used in pharmaceutical preparations, since, they are having anticholinergic, antispasmodic and mydriatic properties. About eleven species are distributed from the Canary islands over Europe and North Africa to Asia. The *H. muticus* and *H. niger* have been introduced in India by the Central Institute of Medicinal and Aromatic Plants and agrotechnology for its large scale cultivation has also been developed (Husain, 1983).

Root-knot Nematodes (*Meloidogyne* Species)

Root-knot nematodes are the main constraint in the cultivation of *Hyoscyamus albus*, *H. muticus* and *H. niger* (Ustinov, 1939; Minz, 1956). The species of root-knot nematodes associated with this crop were first identified as *M. incognita* and *M. javanica* by Anonymous (1985, 1986) and (Haseeb and Pandey, 1989a). In fields, 60-70% plants were infected with the nematode appeared to be chlorotic, stunted in growth, bearing fewer leaves and flowers showing patchy growth of the crop. The roots of such plants were galled to various degrees. Pathogenicity of *M. incognita* and *M. javanica* was established separately on *H. muticus* and *H. niger* (Anonymous, 1986; Haseeb and Pandey, 1989a). Later, Haseeb *et al.* (1990, 1993b) also established the pathogenicity of *M. incognita* on *H. albus*, *H. muticus* and *H. niger*. Haseeb *et al.*, (1990) determined the effect of different initial population densities of *M. incognita* on the disease development, reproduction factor, total alkaloid yield, physiological responses (total leaf chlorophyll, CO_2 exchange rate and concentration of copper, iron, manganese, potassium, sodium and zinc). The increase in initial inoculum potential of the nematode, resulted in corresponding decrease in fresh and dry plant weight, alkaloid yield, total chlorophyll content, photosynthetic rate, sodium, potassium, iron, manganese, copper and zinc in root and shoot. While, the concentration of sodium and potassium increased in shoot. Highest initial population density brought a greatest reduction in all the test parameter of the study. Highest multiplication of nematode was obtained in plants inoculated with 50-second stage larvae of *M. incognita*. Whereas, the multiplication rate of the nematode was decreased maximum at the initial inoculum density of 15,000 juveniles per pot. The age of seedling is an important factor, in determination of pathogenicity of *M. incognita*. In case of *H. muticus* it was investigated by Butool and Haseeb in 1996. They reported that there was an inversely proportional relationship between the age of seedlings and the infection potential of *M. incognita*. Increased damage potential of *M. incognita* to *H.*

niger was noticed when it was inoculated with *P. thornei* (Haseeb *et al.*, 2000a). Effect of different pH levels on the germination, survival and growth of *H. niger* seedlings and damage potential of *M. incognita* was determined by Haseeb *et al.* (1999a); and reported, <pH 8.0 as the optimum pH range for the growth of *H. niger*. The damage of *M. incognita* was also observed directly proportional to pH.

Other Nematodes

In addition to the root-knot nematode, large number of plant parasitic nematode *viz.*, *Tylenchorhynchus vulgaris*, *Hoplolaimus* sp., *Helicotylenchus* sp., *Pratylenchus thornei*, *Rotylenchulus reniformis*, *Xiphinema* sp., *Longidorus* sp. and *Trichodorus* sp. were consistently isolated from the rhizosphere of the test species of henbane. The association of above mentioned nematodes is also a first record (Haseeb and Pandey, 1989a).

Management Studies

Successful attempts have been made to manage *M. incognita* on *H. albus* and *H. muticus* by nematicides and oil cakes (Haseeb and Butool, 1998 and Butool *et al.*, 1998). In both the experiments, application of nematicides and oil cakes suppressed the pathogenic effect of *M. incognita* and resulted in significant reduction in gall intensity and population density of root-knot nematode in roots and soil. Application of spores of *Glomus aggregatum* has also been proved to be effective against *M. incognita* (Butool and Haseeb, 1996). Various tetraploids of *H. muticus* were also tested for identifying the sources of resistance against *M. incognita*.

Ocimum Species (Basil)

Ocimum (family: Labiateae) is a versatile genus with more than 160 species distributed in Africa, tropical Asia, America and sub-tropical regions of the world. The best quality of basil oil is obtained from *Ocimum basilicum* L. (sweet basil) world over. The major constituents of it, are 43-50% linalool, 18-33% menthyl chavicol, 5-6% eugenol and isoeugenol. Whereas, the minor constituents are alpha and beta pinene, camphor, geraniol etc. The oil of sweet basil has very high remunerative value, because its oil has been used in cosmetic, condimentary products, perfumery and confectionary industries, particularly in Europe. In India, *Ocimum* is considered a holy plant. Its stomachic, antihelmintic, alexipharmic, diaphoretic, expectorant, carminative, stimulant and pectoral. The seeds of *O. basilicum* are used in dysentery and chronic diarrhoea. Oil of *O. gratissimum* has repellent property and its use has been suggested for biological control of mosquitoes. Oil of *O. kilmandscharicum* is used in medicines for local application on pain and sprain.

Root-knot Nematodes (*Meloidogyne* Species)

In the past, the *Ocimum* species was known as wild crop and very little attention was paid on the pathology of this crop. *Meloidogyne* sp. for the first time reported on *O. basilicum* by Buhrer (1938). Rangaswami *et al.*, (1961) and Balasubramanian and Rangaswami (1964) reported *O. sanctum* as a host of *M. javanica*. Krishnamurthy and Elias (1967) reported severe infestation of *O. basilicum* with *M. incognita*.

Haseeb *et al.* (1986a; 1987; 1993a, 1996) reported that the major limiting factor in the cultivation of *O. basilicum*, *O. canum* Sims., *O. sanctum*, *O. gratissimum* and *O. kilmandscharicum* Guerke, are the root-knot nematodes (*viz. M. incognita* and *M. javanica*). Haseeb *et al.* (1988a,b, 1993a, 1996, 1998a; 1999c) and Haseeb and Butool (1989) have also established the pathogenicity of *M. incognita* on *O. basilicum* cvs. Indian and French, *O. canum* cv. Kali, *O. sanctum* cvs. Krishna and Shyama and *O. kilmandscharicum* cv. Ram. They have reported that all the test species of basil are equally susceptible to *M. incognita*. With the increase in initial inoculum densities of nematode, there was a corresponding decrease in plant growth and oil yield. Highest development of root-knot and reduction in growth/oil yield was obtained in plants inoculated with highest initial inoculum density *i.e.* 5000 J2/5 kg soil. *O. gratissimum* L. was found highly resistant to *M. incognita*.

Effect of soil types and soil pH on the growth and oil yield of *O. canum* under controlled conditions was studied by Haseeb (1996) and Haseeb *et al.* (1999b, 2000b). Results revealed heavier soils with lower pH as most suitable for the growth and oil yield, escaping better from the damage caused by *M. incognita* as compared to other lighter soils having high pH.

Other Nematodes

Goffart (1931) reported association of *Aphelencoides ritzembosi* with *O. basilicum* and *O. canum* Sims. Haseeb *et al.*, (1986a, 1987) reported association of *Tylenchus* sp., *Tylenchorhynchus vulgaris*, *Hoplolaimus* sp., *Helicotylenchus* sp., *Pratylenchus thornei*, *Rotylenchulus reniformis*, *Xiphinema* sp. and *Longidorus* sp. besides root-knot nematodes with various species of *Ocimum*. Rhoades (1988) studied the effect of *Belonolaimus longicaudatus*, *Dolichodorus heterocephalus*, *Hoplolaimus galeatus*, *Paratrichodorus christiei* and *Pratylenchus scribneri* on the growth of *O. basilicum* in Florida, U.S.A. He reported that the population of *B. longicaudatus*, *P. scribneri* and *P. christiei* were increased significantly and reduced the foliage and root growth within 10 months period. However, *P. christiei* did not reduce root growth. *D.*

heterocephalus also multiplied well on this crop without affecting foliage yield/root growth. *H. galeatus* was not able to cause any damage to this crop.

Management Studies

Experiments have been carried out to control *M. incognita* infesting *O. basilicum, O. canum* and *O. kilmandscharicum* by using hydrodistillation waste of medicinal plants, nematicides and oil cakes. Treatments with nematicides and oil cakes, significantly suppressed the root-knot development and increased the plant growth/oil yield. Neem cake proved to be the best treatment in improvement of plant growth/oil yield and also in suppression of nematode population (Haseeb *et al.*, 1988c, 1998b,c).

Dioscorea Species (Yam)

Dioscorea species belonging to the family Dioscoreaceae is considered as the most important source of diosgenin, a steroidal sapogenin, most commonly used as precursor for synthesis of drugs, which include cortisones, sex hormones and oral contraceptives. According to an estimate, more than 70 per cent of the total requirements of these drugs are obtained from diosgenin. This demand is bound to increase in near future depending upon the family planning programme of the developing countries. Whereas, in India, the estimate requirement is about 60 tonnes. The present production of diosgenin, mainly derived from *D. deltoidea* wall. obtained from the forest of U.P., H.P. and J. & K. the annual production is approximately 15-20 tonnes.

Root-knot Nematodes (*Meloidogyne* Species)

Buhrer (1938) reported for the first time, *D. alata* as the host of *Meloidogyne* species. Hawely (1956) and Schieber (1961) reported that *M. arenaria, M. incognita* and *M. javanica* are the major pest of *D. floribunda* Mart. and Gal. In Guatemala, *D. floribunda* and *D. spiculiflora* Hemsl. were also severely infested with *Meloidogyne* species as reported by Schieber and Lassmann (1961). Jenkins and Bird (1962) found that the wild yam was also subject to the attack of *M. incognita* along with other tylenchid nematodes. *M. incognita* was found to be responsible to the damage to *D. alata* and *D. spinosa* Roxb. in Kerala (Raveendran and Nadakal, 1975) and on *D. rotundata* Poir. (Acosta and Ayala, 1975).

Atu *et al.* (1983) studied the effect of different initial inoculum densities of *M. incognita* ranging from 50 to 156250 eggs per plant of *D. rotundata* cv. Igava. The economic threshold and economic injury levels were fixed at 250 and 1250 nematodes per plant, respectively at a soil temperature of 28°C, the market value of yam tuber was reduced by 40% in plants inoculated with more than 1250 nematodes/plant.

Montalvo and Melendez (1986) studied the interrelationships between *M. incognita* and *P. coffeae* and *Fusarium oxysporum* f. sp. *dioscoreae* on *D. rotundata* cv. Habnero. Histopathological studies indicate that the colonisation of the fungus occurred indiscriminately either inter- or intracellularly after 14, 42 and 72 days of inoculations. Apparently, the nematode as well as fungus colonised different tissues of Yam tuber. However, abundant and vigorous colonisation of hyphae were found in tissues where *M. incognita* was inoculated earlier than fungus.

Other Nematodes

Besides, the root-knot nematods, the yam is susceptible to the attack of other plant parasitic nematodes which decline the total production of tuber and reduce the market value. Steiner (1931) for the first time isolated the *Hoplolaimus* species from the infected yam tuber and the disease was named as "Nematosis". Further, he has identified and described the nematode species as *Hoplolaimus bradys*. Later, in 1958, Andrassy has raised the taxonomic status of the nematode from the species to a genus *Scutellonema*. West (1934) reported that *H. bradys* (= *S. bradys*) was associated with yam tuber in Jamaica. The main symptom of the disease is the lossened cortex of tuber and this condition is known as " dry rot". Similar symptom was noticed by Steiner and Buhrer (1934) in Puerto Rico. *S. bradys* was also found to be associated with *D. alata*, *D. cayenensis* and *D. rotundata*.

Jenkin and Bird (1962) reported that *P. brachyurus* and *Criconemoides* species were associated with wild yam. The association of *Aphelencoides* sp., *Aphelenchus* sp., *Helicotylenchus* sp., *P. coffeae* and *R. reniformis* with *D. rotundata* was reported by Ayala (1966a, b) and Ayala and Acosta (1971) in Puerto Rico. Dixon and Latta (1965) reported that several plant-parasitic nematodes were associated with this crop in Jamaica. Acosta and Ayala (1975) have established the pathogenicity of *S. bradys*, *P. coffeae* and *R. reniformis* on *D. rotundata* cv. Guinea. They have found that the "dry rot" symptom was produced on the tubers. However, *R. reniformis* fails to produce any necrosis or cracking of the cortical tissue on tuber.

Ekundayo and Naqvi (1972) reported that the yam tubers were severely infested in association with *S. bradys* and *Corynebacterium* sp. in Nigeria. The incidence of the disease in terms of "dry rot" and non-sprouting of tubers in fields were abundant in plants infested with both the pathogens.

In Jamaica, *P. coffeae* is considered to be the most serious pest of yam producing "dry rot" condition or "burning. This condition is characterised by cracking in the skin

underlined by a brown, corky rot in the storage tissues. Rot progresses deeper into the yam tissue following harvest and prior to planting or consumtion.

Pogostemon cablin (Patchouli)

Patchouli (*Pogostemon cablin* Benth. Syn. *P. Patchouli* Pallet. Var. Sauvis Hook) is native of the Phillipines and grows in India, Indonesia, Malaysia and Singapore. The essential oil of patchouli is obtained from steam distillation of dried leaves. It is one of the most important essential oils used commercially in the perfumery industries of the world as a base because of its fixative property. The patchouli oil is also used in Ayurvedic medicine to treat nausea, diarrhoea, cold and headache. The patchouli oil is extensively used in food industries as flavour ingredients.

Root-knot Nematodes (*Meloidogyne* Species)

Among the root-knot nematodes *M. incognita*, *M. javanica* and *M. hapla* have been reported to severely affect this crop. Heavy galling on the root system with root-knot nematodes on patchouli resulted in stunting, wilting, defoliation and yellowing of the plants. Krishnaprasad and Reddy (1979) reported the threshold level of *M. incognita* to be 40 juveniles/g soil. They reported 52% loss in dry weight of patchouli by *M. incognita*. The multiplication rate of *M. incognita* was greater in sandy-loam than clay soil.

Other Nematodes

Djiwanti and Momota (1991) reported that besides *Meloidogyne* species, *Pratylenchus brachyurus* is another important nematode of *P. patchouli* in West Jawa.

Trachyspermum Species (Ajwain)

Trachyspermum species (family Apeaceae = Umbelliferae) is an important essential oil bearing crop. Its oil is the major source of thymol, which has wide application in various pharmaceutical preparations. In India its cultivation is mainly being done in the states of Bihar, Gujarat, Madhya Pradesh, Maharashtra, Rajasthan, Uttar Pradesh and West Bengal.

Root-knot Nematodes (*Meloidogyne* Species)

Association of plant parasitic nematodes with *Trachyspermum ammi* was first observed in the experimental fields of CIMAP, Lucknow, and root-knot nematode, *M. incognita* was considered to be the major pest of this crop (Haseeb, 1992, 1994). Butool and Haseeb (1992) established the pathogenicity of *M. incognita* on *T. ammi*. Results

revealed that an initial population of 1J2/g of soil may cause 38-42% reduction in plant weight and very severe galling on roots.

Management Studies

Management of *M. incognita* was successfully done under controlled conditions by Haseeb and Butool in 1993. Ethoprop was found to be most effective followed by carbofuran, neem cake, carbendezim respectively.

Cymbopogon Species (Aromatic Grasses)

Cymbopogon species are the aromatic grasses belonging to the family Graminae have more than 140 species (Sobti *et al.* 1982). Essential oil can be obtained from all parts of the plants except roots (except in *C. jwarancusa*, where roots also contain oil). Essential oil obtained from various grasses are widely used in perfumery and pharmaceutical industries. Further, these oils constitute the natural source of valuable active components *e.g.* citronellal in citronella oil, geranil in palmarose oil and citral in lemongrass oil which again have even more useful in synthesis of new aroma chemicals. Out of many *Cymbopogon* species, the following three are recognised in perfumery and cosmetic industries throughout the world: (i) *Cymbopogon flexuosus* (Nees ex Steud.) Wats (Lemongrass), (ii) *C. martini* (Roxb.) Wats (Palmarosa), (iii) *C. winterianus* Jowitt. (Citronella Java).

There has been tremendous increase in the cultivation of these grasses to meet the requirement of the industry. According to a report, the annual production of citronella, lemongrass and palmarosa oils is approximately 800, 400 and 70 tonnes, respectively.

It has been reported during studies on the association of plant parasitic nematodes with these grasses at CIMAP, Lucknow, that nematodes reproduce well in the rhizosphere of these grasses (Anonymous, 1984, 1985, 1986, 1987a, 1988; Haseeb, 1992-94). Symptoms under field conditions include patchy and stunted growth with reduced number of tillers and severe chlorosis. The most dominant species of the parasitic nematodes were *Tylenchorhynchus vulgaris* and *P. thornei* followed by *Helicotylenchus indicus*, *Hoplolaimus indicus* etc. Studies were also made on the seasonal fluctuation of plant parasitic nematodes associated with lemongrass, palmarosa, citronella and khus. The pathogenicity of *T. vulgaris* and *P. thornei* were established separately on citronella Java. Both the species of nematodes multiplied well and reduced the root growth/herb yield. During studies on combined effect of *P. thornei* and *T. vulgaris* on the herb yield of citronella, population build up and disease development, it was found that combined

inoculation had more profound effect on the growth and oil yield of the plant than when either species of the nematode present alone (Haseeb and Pandey – unpublished).

Other Medicinal Plants of Significance

Other than the above mentioned medicinal plants, several other plants are also known for their economic potentiality as a source of raw material for pharmaceutical industries. Many of them (such as species of *Abrus, Azadirachta, Beta, Brassica, Cajanus, Capsicum, Cicer, Crotolaria, Croton, Glycine, Gossypium. Lathyrus, Lens, Linum, Nicotiana, Piper, Pisum, Ricinus, Trigonella, Vigna* etc.) have been used by mankind as food crops or for various other purposes. Much reseach on nematological problems of these crops has been done and published, therefore these plants are not included in this review. However, still there are many important medicinal plants, which could not get sufficient attention. The list of some important medicinal plants with their important parasitic nematodes is presented hereunder.

List of important medicinal plants and the nematodes associated with them

Plants name	Nematodes species	References
Abelmoschus esculentus (L.) Moench.	*Meloidogyne incognita*	Sasser (1954); Colbran (1958); Nadakal (1964b); Valdez (1968); Atwal and Mangar (1971); Oteifa and Elgindi (1983); Sosa-Moss (1985)
Abutilon avicennae Gaertn.	*Meloidogyne javanica*	Goodey *et al.* (1965)
Abrus precatorius L.	*Hoplolaimus* sp., *Tylenchorhynchus vulgaris*, *Tylenchus* sp.	Alam and Khan (1975)
Abutilon indicum L.	*Hoplolaimus* sp., *Meloidogne incognita acrita, M. incognita, M. javanica, Tylenchorhynchus vulgaris*	Buhrer (1938); Alam and Khan (1975); Bhatti and Dahiya (1977)
Acorus calamus L.	*Helicotylenchus* sp., *Longidorus* sp. *Meloidogyne javanica, Tylenchorhynchus vulgaris, Tylenchus* sp.	Haseeb and Pandey (1987)
Adhatoda vasica Nees.	*Helicotylenchus* sp., *Meloidogyne incognita, M. javanica.*	Dahiya *et al.* (1988); Haseeb *et al.* (1984, 1985); Patel *et al.* (1989)

Albizzia lebbek (L.) Willd	*Meloidogyne incognita, M. javanica, Radopholus similis, Tylenchorhynchus indicus*	Basu and Banerjee (1978); Azmi (1978)
Allium canadense L.	*Meloidogyne incognita*	Gaskin (1958); Goodey *et al.* (1965)
Allium cepa L.	*Meloidogyne incognita, M. javanica*	Sasser (1954); Martin (1958); Goodey *et al.* (1965); Chandwani and Reddy (1967); Decker (1968); Siddiqui *et al.* (1973); Thirugnanum and Rangaswami (1976)
Aloe barbadensis Mill	*Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris*	Sasser (1954); Martin (1958), Goodey *et al.* (1965); Siddiqui *et al.* (1973); Haseeb and Pandey (1987)
Aloe perryi Baker	*Helicotylenchus* sp., *Heterodera* sp., *Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris*	Haseeb and Pandey (1987)
Alipina galanga (L.) Sw.	*Aphelencoides* sp., *Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne javanica, Tylenchorhynchus vulgaris, Pratylenchus* sp.	Haseeb and Pandey (1987)
Ammi majus L.	*Aphelencoides* sp., *Helicotylenchus* sp., *Meloidogyne arenaria, M. incognita, M. javanica, Tylenchorhynchus vulgaris*	Martin (1959); Haseeb and Pandey, 1987; Pandey (1992)
Ammi visnaga L.	*Aphelencoides* sp., *Helicotylenchus* sp., *Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris*	Haseeb *et al.* (1984, 1985)

Andrographis paniculatus (Burm. F) Nees	*Helicotylenchus* sp., *Mincognita incognita, Pratylenchus* sp., *Tylenchorhynchus vulgaris*	Haseeb and Pandey (1987)
Anethum graveolens L.	*Meloidogyne incognita*	Valdez (1968)
Anthocephalus cadamba Roxb.	*Meloidogyne javanica*	Gupta and Dalal (1973)
Apium graveolens L. Wall Ex. Nees	*Belonolaimus longicaudatus, Ditylenchus dipsacii, D. destructor, Hemicycliophora arenaria, Hoplolaimus* sp., *Longidorus maximus, Meloidogyne incognita acrita, M. incognita, M. hapla, M. javanica, Pratylenchus penetrans, Tylenchus* sp., *Tylenchorhynchus vulgaris*	Oostenbrink *et al.* (1957); Colbran (1958); Hunt (1959); Kuhn (1959); Gundy and Rackham (1961); Rau (1963); Decker, 1968; Siddiqui *et al.*, 1973; D'Errico *et al.* (1991)
Argyreria speciosa Sweet	*Helicotylenchus* sp., *Meloidogyne incognita, Pratylenchus* sp., *Tylenchorhynchus vulgaris*	Minz (1963); Haseeb and Pandey (1989b)
Artemisia pallens L.	*Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Tylenchorhynchus vulgaris, Tylenchus* sp.	Haseeb and Pandey (1990)
Asclepias curassavica L.	*Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Tylenchorhynchus vulgaris*	Colbran (1958); Goodey *et al.* (1965); Haseeb and Pandey (1987)
Asparagus racemosus Willd.	*Helicotylenchus* sp., *Hoplolaimus* sp., *Hirschmaniella* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris, Tylenchus* sp.	Franklin (1940); Mcmillen (1941); Haseeb *et al.* (1984); Upadhyay and Swarup (1972); Dahiya *et al.* (1988)

Atropa belladonna L.	*Heterodera rostochiensis, Hoplolaimus* sp., *Longidorus brevicaudatus, Meloidogyne* sp., *Pratylenchus penetrans, Tylenchorhynchus vulgaris*	Khan and Khan (1972)
Bacopa monnieri (L.) Wettstein	*Helicotylenchus* sp., *Longidorus* sp., *Meloidogyne incognita, Tylenchorhynchus vulgaris*	Haseeb *et al.* (1984)
Barlaria pionitis L.	*Meloidogyne incognita*	Haseeb and Shukla (unpublished)
Barringtonia acutangula L. Gaertn.	*Hirschmaniella* sp., *Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris, Tylenchus* sp.	Haseeb and Pandey (1987)
Boerhavia diffusa L.	*Hoplolaimus* sp., *Meloidogyne javanica, M. incognita, Pratylenchus* sp., *Tylenchorhynchus vulgaris,*	Rangaswami *et al.* (1961); Balasubramaniyan and Rangaswami (1964); Haseeb *et al.* (1984)
Borreria hispida Schum.	*Meloidogyne incognita*	Roy (1972)
Borreria ocymoides	*Meloidogyne incognita*	Nadakal (1964b)
Callistemon citrinus Skeel	*Helicotylenchus* sp., *Longidorus* sp., *Meloidogyne incognita, Trichodorus* sp., *Tylenchus* sp., *Tylenchorhynchus vulgaris*	Goodey *et al.* (1965); Haseeb and Pandey (1987)
Callistemon lanceolata Dc.	*Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Tylenchorhynchus vulgaris,*	Haseeb and Pandey (1987)
Calotropis gigantea L. R. Br. Ex. Ait.	*Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris,*	Lal *et al.* (1976, 1977); Haseeb *et al.* (1984)
Calotropis procera Bry.	*Hirschmaniella* sp., *Longidorus* sp., *Meloidogyne incognita, Tylenchorhynchus vulgaris*	Sethi and Swarup (1968); Alam *et al.* (1976)

Cannabis sativa L.	*Ditylenchus dipsaci, Helicotylenchus erythrinae, Heterodera humuli, H. schachtii, Longidorus maximus, Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris,*	Hollrung (1890); Steiner and Buhrer (1932); Buhrer *et al.* (1933); Winslow (1954); Sturhan (1963); Khan *et al.* (1964); Nirula and Kumar (1964); Goodey *et al.* (1965); Upadhyay and Swarup (1972); Bhatti and Dahiya (1977)
Capsicum annum L.	*Meloidogyne arenaria, M. incognita*	Goodey *et al.* (1965); Valdez (1968); Rajgopalan and Seshadri (1969); Raveendran and Nadakal (1975); Netscher and Taylor (1979)
Capsicum frutescens	*Meloidogyne incognita*	Lal and Ansari (1960); Goodey *et al.* (1965); Bos (1978)
Cassia angustifolia Vahl.	*Helicotylenchus* sp., *Hoplolaimus* sp., *Heterodera* sp., *Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Tylenchorhynchus vulgaris*	Patel *et al.* (1989)
Cassia occidentalis L.	*Meloidogyne incognita, Meloidogyne incognita acrita, M. arenaria, Pratylenchus pratensis*	Thorne (1936); Luc and Deguiran (1960); Alam *et al.* (1976)
Cassia tora L.	*Helicotylenchus* sp., *Hoplolaimus indicus, Longidorus* sp., *Meloidogyne javanica, M. arenaria, Pratylenchus* sp., *P. coffeae, Rotylenchulus reniformis, Tylenchus* sp., *Tylenchorhynchus vulgaris*	Atkinson (1889); Steiner (1949); Machmer (1951); Nirula and Kumar (1963); D'souza and Kashivishwanathan (1969); Khan *et al.* (1964); Lal *et al.* (1978)
Catharanthus roseus (L.) Don	*Helicotylenchus* sp., *Meloidogyne incognita, Pratylenchus* sp., *Rotylenchus* sp., *Tylenchorhynchus vulgaris*	Goodey *et al.* (1965); Roy (1972); Anonymous (1984-85); Haseeb and Pandey (1987)

Celastrus paniculatus Willd.	*Helicotylenchus* sp., *Meloidogyne javanica, Pratylenchus brachyurus*	Haseeb and Pandey (1987)
Chrysanthemum cinerifolium	*Aphelecoides ritzembosi, Ditylenchus dipsaci, Meloidogyne hapla, M. javanica, Pratylenchus* sp., *Rotylenchulus reniformis*	Edward (1955); Lordello (1957); Luc and DeGuiran (1960)
Cissus qyadrangularis L.	*Meloidogyne incognita*	Haseeb *et al.* (1984); Haseeb and Pandey (1987)
Clitoria ternatea L.	*Helicotylenchus* sp., *Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris, Pratylenchus* sp.	Alam (1981); Azmi (1978); Nadakal (1964b)
Cichorium intybus L.	*Ditylenchus dipsaci, Hoplolaimus indicus, Meloidogyne arenaria, M. incognita, M. hapla, M. javanica, Pratylenchus penetrans, P. pratensis, Rotylenchulus reniformis*	Licopoli (1877); Geisenheyner (1902); Baudys (1948); Martin (1954); Oostenbrink (1954); Gaskin and Crittenden (1956); Loof (1960); Mai *et al.* (1960); Steiner and Buhrer (1932b)
Coleus aromaticus Benth.	*Meloidogyne incognita, Tylenchorhynchus vulgaris, Pratylenchus* sp.	Raveendran and Nadakal (1975)
Coleus blumei	*Meloidogyne incognita*	Maqbool *et al.* (1985)
Coleus forskohlii Benth.	*Meloidogyne incognita, M. javanica*	Patel *et al.* (1989); Haseeb *et al.* (2000c)
Commiphora wightii Jacq.	*Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Tylenchorhynchus vulgaris*	Bessey (1911); Georghiou (1957); Haseeb *et al.* (1984, 1985)
Convolvulus microphyllus Sieber. Ex. Spreng.	*Meloidogyne incognita, M. javanica, Pratylenchus* sp.	Haseeb *et al.* (1984, 1985)

Coriandrum sativum L.	*Heterodera oryzae, Meloidogyne incognita acrita, M. incognita, M. javanica, Pratylenchus thornei, Rotylenchulus reniformis, Tylenchorhynchus vulgaris*	Chandwani and Reddy (1967); Krishnamurthy and Elias (1967); Upadhyay and Swarup (1972); Sen and Dasgupta (1977); Das and Sultana (1979); Greco *et al.* (1988)
Costus speciosus Koen. Ex. Retz. Sm	*Heterodera* sp., *Hoplolaimus* sp., *Meloidogyne incognita, Tylenchus* sp., *Tylenchorhynchus vulgaris*	Haseeb and Pandey (1987)
Crataeva nurvalo Ham.	*Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris*	Haseeb and Pandey (1987)
Cuminum cyminum L.	*Meloidogyne incognita, M. incognita acrita, M. javanica, Rotylenchulus reniformis, Tylenchorhynchus brevidens, T. vilineatus*	Siddiqi (1961, 1963); Swarup *et al.* (1967); Sethi and Swarup (1968); Verma and Prasad (1969); Shah and Patel (1979)
Curculigo orchioides Gaertn.	*Meloidogyne incognita*	Nadakal (1964b)
Curcuma amada Roxb.	*Meloidogyne incognita, M. javanica, Radopholus similis, Tylenchorhynchus vulgaris*	Sen and Dasgupta (1977); Sosamma and Koshy (1981)
Curcuma cyminum	*Meloidogyne incognita*	Shah and Patel (1979)
Curcuma longa Auct. Non. L.	*Helicotylenchus multicinctus, Heterodera trifolii, Meloidogyne incognita, M. javanica, Radopholus similis, Rotylenchus reniformis, Tylenchorhynchus mashoodi, T. vulgaris*	Ayyar (1933); Koshy and Sosamma (1975); Nadakal and Thomas (1964); Nirula and Kumar (1964); Sosamma *et al.* (1979); Ray and Das (1980); Patel *et al.* (1981)
Cymbopogon flexuosus L.	*Helicotylenchus* sp., *Rotylenchulus reniformis, Tylenchorhynchus brassicae, T. vulgaris, Tylenchulus semipenetrans*	Anonymous (1984-85); Siddiqi and Alam (1988)

Cymbopogon martini (Roxb.) Wats.	*Helicotylenchus dihystera*	Azmi (1978)
Cyperus rotundus L.	*Meloidogyne javanica*	Goodey *et al.* (1965); Bhatti *et al.* (1974)
Datura arborea L.	*Meloidogyne incognita*	Kiryanova and Krall (1980)
Datura metel L.	*Meloiogyne incognita, Pratylenchus* sp., *Tylenchorhynchus vulgaris*	Khan *et al.* (1964)
Datura stramonium L.	*Meloidogyne arenaria, M. javanica, M. hapla, Tylenchorhynchus vulgaris*	Martin (1958); Lal *et al.* (1976);
Desmodium gangeticum (L.) DC.	*Helicotylenchus* sp., *Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris*	Haseeb *et al.* (1984, 1985)
Digitalis lanata Ehrh.	*Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne arenaria, M. thamesi, M. incognita acrita, M. incognita, M. javanica, Tylenchus* sp., *Tylenchorhynchus vulgaris*	Licopoli (1877); Oostenbrink *et al.* (1957); Minz (1958); Goodey *et al.* (1965); Haseeb and Pandey (1987)
Digitalis purpurea L.	*Aphelencoides fragrarae, Ditylenchus. dipsaci, Helicotylenchus* sp., *Hoplolaimus* sp., *Meloidogyne incognita, M. arenaria, M. hapla, Pratylenchus penetrans, Tylenchus* sp., *Tylenchorhynchus vulgaris*	Steiner and Buhrer (1932); Junges (1938); Oostenbrink *et al.* (1957); Landhardt (1963); Haseeb and Pandey (1987)
Dioscorea alata L.	*Hemicycliophora utkali, Meloidogyne incognita, Pratylenchus brachyurus, Scutellonema bradys*	Buhrer (1938); Luc and DeGuiran (1960); Nadakal and Thomas (1967); Raveendran and Nadakal (1975); Ray and Das (1980)

Dioscorea composita Hemsl.	*Helicotylenchus* sp., *Heterodera* sp., *Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne arenaria, M. incognita, Tylenchorhynchus vulgaris, Tylenchus* sp.	Schieber (1961); Goodey *et al.* (1965)
Dioscorea floribunda Mart. and Gal.	*Heterodera* sp., *Meloidogyne arenaria, M. incognita, M. incognita acrita, M. javanica, Tylenchorhynchus vulgaris, Tylenchus* sp.	Hawley (1956); Schieber (1961); Goodey *et al.* (1965)
Dioscorea rotundata Poir.	*Meloidogyne incognita*	Caveness (1979)
Dioscorea spinosa Roxb.	*Meloidogyne incognita*	Raveendran and Nadakal (1975)
Dolichos biflorus L.	*Meloidogyne incognita, M. javanica*	Bessey (1911); Chandwani and Reddy (1967); Koshy and Swarup (1972); Raveendran and Nadakal (1975); Ray and Das (1980)
Duboisia myoporoides R. Br.	*Helicotylenchus imperialis, Meloidogyne incognita, M. javanica, Pratylenchus coffeae, Tylenchorhynchus digitatus*	Kelenyi (1949); Colbran (1958); Varaprasad *et al.* (1987)
Eclipta alba (L.) Hassk.	*Meloidogyne graminicola, M. incognita, M. javanica*	Bessey (1911); Colbran (1958); Nadakal and Thomas (1964); Chidamberanathan and Rangaswami (1965); Naqvi and Alam (1974); Lal *et al.* (1977); Rao and Jaiprakash (1978)
Elettaria cardamomum (L.) Maton.	*Crossonema tylatum, Hemicycliophora argiensis, Nothocriconema cardamomi, N. cooroi, Meloidogyne incognita, M. javanica*	Khan and Nanjappa (1972); Khan *et al.* (1975); Sosa-Moss (1985)

Eleusine indica (L.) Gaertn.	*Meloidogyne incognita, M. arenaria*	Martin (1958); Goodey, *et al.* (1965); Barnes and Gowen (1969); Roy (1972); Naqvi and Alam (1974); Wang (1978); Tedford (1986)
Elytraria acualis Lindau.	*Hirschmanniella oryzae, Meloidogyne graminicola, M. incognita, M. javanica, Tylenchorhynchus vulgaris*	Rao and Jaiprakash (1978); Haseeb *et al.* (1984); Haseeb and Pandey (1987)
Euphorbia thymipholia L.	*Meloidogyne incognita*	Haseeb *et al.* (1984)
Euphorbia tirucalli L.	*Meloidogyne incognita, M. javanica*	Sharma and Haseeb (Unpublished)
Flacourtia indica Merr.	*Meloidogyne javanica*	Haseeb and Pandey (1987)
Geranium carolinianum L.	*Meloidogyne incognita*	Goodey *et al.* (1965); Pandey and Haseeb (1997)
Glycyrrhiza glabra L.	*Aphelenchus avenae, Pratylenchus* sp., *Tylenchorhynchus vulgaris*	Mathur *et al.* (1980)
Gymnema sylvestre R. Br.	*Meloidogyne javanica*	Haseeb and Pandey (1987)
Hemidesmus indicus (L.) Br.	*Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris*	Haseeb *et al.* (1984); Patel *et al.* (1989)
Hibiscus rosa sinensis L.	*Aphelencoides andrassyia, A. jacobi, A. ritzembosi, Hemicycliophora similis, Hoplolaimus* sp., *Longidorus maximus, L. sativa, Meloidogyne arenaria, M. incognita, M. incognita acrita, M. javanica, M. hapla, Naccobus batatiformis, N. serendipiticus, Paratylenchus projectus, P. penetrans, Pratylenchus pratensis, P. coffeae, P. loosi, Radopholus similis, Rotylenchulus reniformis, Tetylenchus joctus, Tylenchorhynchus christiei, T. claytoni, T. chonai*	Bessey (1911); Birchfield (1956); Martin (1958); Husain and Khan (1967b); Swarup *et al.* (1967); Sethi and Swarup (1968); Alam *et al.* (1976); Chitambar and Gupta (1977)

Humulus lupulus L.	*Ditylenchus destructor, D. dipsaci, Heterodera humuli, H. shachtii, Meloidogyne hapla, M. incognita, M. javanica, Xiphinema americanum*	Pericival (1895); Nance (1941); Jones (1950); Goodey (1952); Martin (1958); Maggenti and Hart (1963)
Hygrophylla auriculata R. Br.	*Helicotylenchus* sp., *Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Tylenchus* sp., *Tylenchorhynchus vulgaris*	Haseeb and Pandey (1987);
Hyoscyamus albus L.	*Helicotylenchus* sp., *Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Rotylenchulus reniformis, Trichodorus* sp., *Tylenchus* sp., *Tylenchorhynchus vulgaris, Xiphinema* sp.	Haseeb and Pandey (1989a)
Hyoscyamus muticus L.	*Helicotylenchus* sp., *Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Rotylenchulus reniformis, Trichodorus* sp., *Tylenchus* sp., *Tylenchorhynchus vulgaris, Xiphinema* sp.	Ustinov (1939); Oostenbrink (1950); Minz (1956); Goodey *et al.* (1956); Haseeb and Pandey (1989a); Vanha and Stoklasa (1996)
Hyoscyamus niger L.	*Ditylenchus dipsaci, Globodera rostochiensis, Longidorus* sp., *Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Rotylenchulus reniformis, Trichodorus* sp., *Tylenchus* sp., *Tylenchorhynchus vulgaris, Xiphinema* sp.	Goodey *et al.* (1956); Haseeb and Pandey (1989a)

Indigofera tinctoria L.	*Heterodera glycines, Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris*	Riggs and Hamblen (1967); Haseeb *et al.* (1984)
Ipomoea hederacea Jacq.	*Longidorus* sp., *Meloidogyne incognita, M. incognita acrita, Pratylenchus* sp., *Tylenchorhynchus vulgaris*	Gaskin (1958); Haseeb *et al.* (1984)
Ixora arborea Roxb. Ex. Sm.	*Meloidogyne javanica*	Haseeb and Pandey (1987)
Ixora coccinea L.	*Meloidogyne incognita, Radopholus similis, Tylenchorhynchus vulgaris*	Goffart (1953); Brooks (1954, 1955); Haseeb and Pandey (1987)
Jasminum humile L.	*Meloidogyne javanica*	Haseeb and Pandey (1987)
Jasminum nudiflorum Linde.	*Meloidogyne incognita*	Goodey *et al.* (1965)
Jasminum humile L.	*Meloidogyne javanica, Tylenchorhynchus vulgaris*	Haseeb and Pandey (1987)
Lactuca sativa L.	*Meloidogyne incognita, M. javanica*	Colbran (1958); Goodey *et al.* (1965)
Lavandula officinalis Chaix.	*Aphelecoides ritzembosi, Ditylenchus dipsaci, Meloidogyne javanica*	Buhrer (1938); Junges (1938); Kirijanova (1939); Minz (1956)
Lepidium sativum L.	*Ditylenchus dipsaci, Heterodera cruciferae, H. schachtii, Meloidogyne incognita, M. javanica, M. hapla, Tylenchorhynchus vulgaris*	Kuhn (1881); Voigt (1890); Quanjer (1927); Franklin (1945); Gaskin and Crittenden (1956); Colbran (1958)
Leucas aspera Spreng.	*Meloidogyne incognita*	Nadakal (1964b)
Leucas lanata Benth.	*Meloidogyne incognita*	Roy (1972)

Linum usitatissimum L.	*Ditylenchus dipsaci, Hoplolaimus indicus, Longidorus maximus, Meloidogyne incognita, M. incognita acrita, M. javanica, M. hapla, Pratylenchus coffeae, P. penetrans, Rotylenchulus reniformis, Tylenchorhynchus brevidens, T. phaseoli, T. maxima, T. vulgaris*	Bos (1903); Sorauer (1906); Linde (1956); Colbran (1958); Baker (1959); Sturhan (1963); Sethi and Swarup (1968); Upadhyay and Swarup (1972); Rashid *et al.* (1973); Roy (1973)
Matricaria chamommilla L.	*Helicotylenchus* sp., *Hoplolaimus* sp., *Longidorus* sp., *L. maximus, Meloidogyne hapla, Pratylenchus* sp., *Tylenchus* sp., *Tylenchorhynchus vulgaris*	Nagakura (1930); Gillard and Brande (1956); Sturhan (1963)
Melissa officinalis L.	*Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Pratylenchus* sp., *P. pratensis, Tylenchorhynchus vulgaris, Paratylenchus microphyllus*	Goodey *et al.* (1956); Haseeb *et al.* (1984)
Mentha arvensis L.	*Ditylenchus dipsaci, D. destructor, Helicotylenchus* sp., *Hoplolaimus* sp., *Heterodera* sp., *H. shachtii, Hirschmanniella orycrena, Longidorus pisi, Meloidogyne incognita, M. javanica, M. hapla, Trichodorus* sp., *Pratylenchus exilis, P. thornei, Rotylenchulus* sp., *Tylenchus* sp., *Tylenchorhynchus vulgaris, Xiphinema* sp.	Buhrer (1938); Hurst (1948); Goffart (1953, 1957); Newton and Duthoit (1954); Sultana (1978); Das and Sultana (1979); Haseeb and Pandey (1989b)

Mentha cardiaca Baker	*Helicotylenchus* sp., *Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Paratylenchus hamatus, Rotylenchulus* sp., *Tylenchus* sp., *Tylenchorhynchus vulgaris*	Anonymous (1984, 1985); Haseeb and Pandey (1989b)
Mentha citrata Ehrh.	*Helicotylenchus* sp., *Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Rotylenchulus* sp., *Tylenchus* sp., *Tylenchorhynchus vulgaris*	Anonymous (1984, 1985); Haseeb and Pandey (1989)
Mentha piperita L.	*Aphelencoides ritzembosi, Helicotylenchus* sp., *Hoplolaimus* sp., *Heterodera* sp., *Longidorus* sp., *L. elongatus, L. menthasolanus, L. salphaye, Meloidogyne chitwoodi, M. incognita, M. javanica, M. hapla, Pratylenchoides laticauda, Pratylenchus* sp., *P. microphyllus, Rotylenchulus reniformis, Tylenchus* sp., *Tylenchorhynchus vulgaris,*	Horner and Jensen (1954); O' Bannon *et al.* (1982); Maqbool *et al.* (1985); Haseeb and Pandey (1989); Esmenjaud *et al.* (1990)
Mentha spicata L.	*Aphelencoides fragararae, Belanolaimus longicaudatus, Helicotylenchus* sp., *Hoplolaimus* sp., *Heterodera* sp., *Longidorus* sp., *Meloidogyne chitwoodi, M. incognita, M. javanica, M. hapla, Paratrichodorus christiei, Paratylenchus hamatus, Pratylenchus scribneri, Tylenchus* sp., *Tylenchorhynchus vulgaris, Xiphinema americana*	Horner and Jensen (1954); O' Bannon *et al.* (1982); Haseeb and Pandey (1989); Inserra and Rhoades (1989)

Mentha viridis L.	*Helicotylenchus* sp., *Hoplolaimus* sp., *H. indicus, Heterodera* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Paratylenchus hamatus, Xiphinema americana*	Haseeb and Pandey (1989)
Nerium oleander L.	*Meloidogyne incognita*	Goodey *et al.* (1965)
Nigella sativa L.	*Meloidogyne incognita*	Haseeb *et al.* (1984)
Ocimum basilicum L.	*Belanolaimus longicaudatus, Dolichodorus hereocephalus, Helicotylenchus* sp., *Hoplolaimus galeatus, Longidorus* sp., *Meloidogyne incognita, M. javanica, M. arenaria thamesi, M. incognita acrita, M. hapla, Pratylenchus scribneri, Paratrichodorus christiei, Rotylenchulus reniformis, Tylenchus* sp., *Tylenchorhynchus vulgaris*	Breda (1899); Ahmad and Khan (1960); Linde *et al.* (1959); Krishnamurthy and Elias (1967); Haseeb and Pandey (1987); Rhoades (1988)
Ocimum canum Sims.	*Criconemella basili, Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Tylenchorhynchus vulgaris*	Ustinov (1939); Haseeb and Pandey (1987); Muthukrishnan (1987)
Ocimum gratissimum L.	*Helicotylenchus* sp., *Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Rotylenchulus reniformis, Tylenchus* sp., *Tylenchorhynchus vulgaris*	Haseeb and Pandey (1987)
Ocimum kilmandescharicum Guerke	*Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Tylenchus* sp., *Tylenchorhynchus vulgaris*	Balasubramanian and Rangaswami (1964); Rangaswami *et al.* (1961); Roy (1972)

Ocimum sanctum L.	*Criconemella basili, Helicotylenchus* sp., *Hemicriconemoides communis, Hoplolaimus indicus, Longidorus* sp., *Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Tylenchorhynchus vulgaris, Tylenchus* sp.	Balasubramanian and Rangaswami (1964); Roy (1972); Muthukrishnan (1987); Haseeb and Pandey (1987)
Operculina terpenthum (L.) S. Manso.	*Longidorus* sp., *Meloidogyne incognita, T. vulgaris*	Haseeb and Pandey (1987)
Oxalis corniculata L.	*Meloidogyne incognita, M. javanica*	Bassey (1911); Martin (1954); Ahmad and Khan (1960); Wang (1978)
Oxalis latifolis HB and K	*Meloidogyne arenaria, Tylenchorhynchus vulgaris*	Martin (1958); Haseeb *et al.* (1984)
Paederia scandans (Lour) Merr.	*Meloidogyne incognita, M. javanica*	Haseeb and Pandey (1987)
Papaver somniferum L.	*Ditylenchus dipsaci, Hoplolaimus* sp., *Longidorus* sp., *L. maximus, Meloidogyne* sp., *Pratylenchus pratensis, P. penetrans, Tylenchus* sp., *Tylenchorhynchus vulgaris*	Buhrer (1938); Baudys (1948); Goffart (1951a); Oostenbrink *et al.* (1957); Loof (1960); Sturhan (1963)
Pelargonium graveolens	*Helicotylenchus* sp., *H. dihystera, Meloidogyne incognita, M. hapla, Scutellonema conicephalum, Tylenchus* sp., *Tylenchorhynchus vulgaris*	Steiner (1949); Arumugam and Kumar (1979); Kumar and Nanjan (1985)
Phyllanthus fraternus Webster	*Meloidogyne incognita*	Alam and Khan (1975)

Piper betle L.	*Criconemella parvula, Helicotylenchus dihystera, H. microcyphallus, H. indicus, Hirschmanniella mucronata, Hoplolaimus indicus, Meloidogyne arenaria, M. incognita, M. incognita acrita, Pratylenchus coffeae, P. zeae, Rotylenchulus reniformis, Tylenchorhynchus indicus, Xiphinema diversicaudatum*	Zimmermann (1899); Dhande and Sulaiman (1961); Martin (1961); Anonymous (1966); Mammen (1974); Raveendran and Nadakal (1975); Sosamma and Koshy (1981); Jagdale *et al.* (1986); Sundaraju and Suja (1986); Sivakumar and Marimuthu (1986); Achrya *et al.* (1988)
Piper longum L.	*Meloidogyne incognita*	Haseeb *et al.* (1984)
Piper nigrum L.	*Helicotylenchus erythrinae, H. trivandranus, Hoplolaimus, seinhorstii, Meloidogyne incognita, M. javanica, Trophotylenchulus piperis, Xiphinema ifacolum*	Zimmermann (1899); Delacroix (1901, 1902); Goodey *et al.* (1956); Luc and Guiran (1960); Nadakal (1964b); Valdez (1968); Mohandas (1975); Koshy *et al.* (1977); Sosamma and Koshy (1981); Lamberti *et al.* (1983); Mohandas *et al.* (1985)
Pluchea lanceolata (DC.) Clark	*Meloidogyne incognita, M. javanica*	Haseeb *et al.* (1984, 85)
Plumbago zeylanica L.	*Helicotylenchus* sp., *Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Tylenchus* sp., *Tylenchorhynchus vulgaris*	Harris (1938); Haseeb *et al.* (1984, 85)
Pogostemon cablin Benth.	*Helicotylenchus dihystera, Hemicriconemoides* sp., *Hoplolaimus* sp., *Longidorus pisi, Meloidogyne hapla, M. incognita, M. incognita acrita, M. javanica, Pratylenchus brachyurus, P. coffeae, P. thornei, Rotylenchulus* sp., *Scutellonema* sp., *Tylenchus* sp., *Tylenchorhynchus vulgaris, Xiphinema americanum*	Fluiter and Mulholland (1941); Kumar and Nanjan (1984); Djiwanti and Momota (1991)

Polygonum plebeium R. Br. Pred.	*Meloidogyne incognita, M. javanica*	Colbran (1958); Haseeb *et al.* (1984); Dahiya *et al.* (1988)
Psoralea corylifolia L.	*Longidorus* sp., *Meloidogyne incognita, M. javanica, Pratylenchus* sp., *Tylenchus* sp., *Tylenchorhynchus vulgaris*	Haseeb *et al.* (1984, 1985)
Punica granatum L.	*Basiria graminophila, Caloosia delpradio, Ditylenchus minutus, Hemicriconemoides mangiferae, Hoplolaimus indicus, Longidorus brevicaudatus, Macroposthonia macrolobatus, M. incognita, Meloidogyne incognita acrita, M. javanica, Pratylenchus lepidus, P. coffeae, Pratylencoides crenicauda, Psilenchus neoformis, Quinisulcius punici, Rotylenchulus reniformis, Seriespinula punici, Tylenchorhynchus brassicae, T. mashoodi, Tylenchulus semipenetrans, Xiphinenema americanum, X. basiri, X. nagarjunensis*	Bessey (1911); Buhrer (1938); Minz (1943, 1956a); Jairajpuri and Siddiqui (1963b); Jairajpuri (1964); Husain and Khan (1967c); Yadav and Verma (1967); Edward *et al.* (1971); Alam *et al.* (1973); Khan and Khan (1973); Rashid *et al.* (1973); Roy (1973); Khan *et al.* (1975); Phukan and Sanwal (1979); Shah and Patel (1979); Gupta and Uma (1980)
Rauwolfia canesscens L.	*Meloidogyne incognita*	Kiryanova and Krall (1980)
Rauwolfia serpentina (L.) Benth. Ex. Kurz.	*Helicotylenchus* sp., *Meloidogyne incognita, Xiphinema* sp.	Hunt (1958); Haseeb *et al.* (1984)
Ricinus communis L.	*Aphelencoides asterocaudatus, A. bicaudatus, A. suntenuis, A. franklini, Aphelenchus avenae, Basiliophora castori, B. propora, Caloosia delpradio, Helicotylenchus dihystera, H. indicus, H. multicinctus, Hirschmanniella mucronata, Hoplolaimus indicus,*	Buhrer (1938); Ustinov (1939); Jensen (1953); Tarjan (1953b); Birchfield (1956); Gaskin and Crittenden (1956); Linde (1956); Minz (1956a); Martin (1958); Linde *et al.* (1959); Das (1960); Mc Bride *et al.* (1961); Seshadri and Sivakumar (1963); Chandrasekaran (1964);

	Longidorus bravicaudatus, Meloidogyne incognita, M. incognita acrita, M. javanica, M. arenaria, M. thamesi, Paralongidorus citri, P. flakkensis, R.adopholus similis, Rotylenchulus. reniformis, Tylenchorhynchus acutus, T. brassicae, T. phaseoli, T. mashoodi, Xiphinema baseri, X. index	Chandwani and Reddy (1967); Husain and Khan (1967a); Swarup *et al.* (1967); Sethi and Swarup (1968); Khan and Khan (1972, 73); Nath *et al.* (1969); Verma and Prasad (1969); Siddiqui *et al.* (1972); Rashid *et al.* (1973); Mukhopadhyay and Haque (1974); Mukherjee and Dasgupta (1979, 1981)
Ruta graveolens L.	*Longidorus* sp., *Meloidogyne* sp., *Tylenchorhynchus vulgaris*	Buhrer (1938)
Salvea sclarea L.	*Meloidogyne incognita, M. javanica, M. hapla*	Minz (1963); Upadhyay and Swarup (1972); Haseeb *et al.* (1985)
Sambucus nigra L.	*Meloidogyne* sp., *Pratylenchus* sp., *Tylenchorhynchus vulgaris, T. martini*	Gram and Rostrup (1924)
Scoparia dulcis L.	*Helicotylenchus* sp., *Hemicycliophora thienemanni, M. incognita, M. incognita acrita, M. javanica, Trichodorus teres, Tylenchorhynchus martini, T. vulgaris, Tylenchus* sp.	Anonymous (1987b, c); Colbran (1958); Fajardo and Palo (1933); Haseeb and Pandey (1987); Luc and De Guiran (1960)
Sesamum indicum L.	*Meloidogyne. incognita*	Raveendran and Nadakal (1975)
Sida cordifolia	*Aphelencoides* sp., *Heterodera* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, M. arenaria, Tylenchus* sp., *Tylenchorhynchus vulgaris*	Colbran (1958); Martin (1959a); Khan and Alam (1974); Alam *et al.* (1976); Lal *et al.*, (1977)
Sida rhombifolia L.	*Meloidogyne incognita, M. incognita acrita, M. javanica, Pratylenchus zeae*	Bessey (1911); Colbran (1958); Luc and DeGuiran (1960); McBride *et al.* (1961); Blake (1963); Nadakal and Thomas (1964); Nirula and Kumar (1966); Lal *et al.* (1977)

Solanum incanum L.	*Meloidogyne incognita, Tylenchus* sp.	Jack (1943); Haseeb *et al.* (1984)
Solanum indicum L.	*Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris*	Martin (1958); Nadakal (1964b)
Solanum khasianum Clarke	*Meloidogyne incognita*	Goodey *et al.* (1965)
Solanum nigrum L.	*Aphelenchus avenae, A. ritzembosi, A. composticola, Ditylenchus dipsaci, Heterodera rostochiensis, H. shachtii, H. tabacum, Meloidogyne arenaria, M. hapla, M. incognita, M. incognita acrita, M. graminicola, Naccobus serendipitcus, Pratylenchus penetrans, Rotylenchulus reniformis, Radopholus similis, Tylenchorhynchus vulgaris*	Vanha and Skolosa (1896); Bessey (1911); Franklin (1940, 1959); Linford and Yap (1940); Tarjan (1953b); Brook (1955); Nolte (1957); Colbran (1958); Gaskin (1958); Prasad (1960a, b); Townshend and Davidson (1960); Balasubramaniam and Rangaswami (1964); Chandsekaran (1964); Prasad *et al.* (1964); Upadhyay and Swarup (1972); Koshy and Sosamma (1975); Lal *et al.* (1977)
Solanum sisymbrifolium Lam.	*Meloidogyne incognita, M. javanica*	Haseeb *et al.* (1984, 1985)
Solanum xanthocarpum Schrad. And Wendl.	*Meloidogyne incognita, Heterodera rostochiensis*	Buhrer (1938)
Spilanthes acmella Murr.	*Aphelencoides ritzembosi, Helicotylenchus* sp., *Hirschmanniella* sp., *Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, Pratylenchus* sp., *Tylenchus* sp., *Tylenchorhynchus vulgaris*	Junges (1938); Luc and DeGuiran (1960); Haseeb *et al.* (1984); Pandey and Haseeb (1989)

Tamarix gallica Auct.	*Hoplolaimus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris*	Gundy *et al.* (1959); Haseeb *et al.* (1984); Haseeb and Pandey (1987)
Trachyspermum ammi Sprague	*Meloidogyne incognita, Rotylenchulus reniformis*	Sethi *et al.* (1964)
Tribulus terrestris L.	*Helicotylenchus* sp., *Meloidogyne incognita, M. incognita acrita, Naccobus batatiformis, Pratylenchus zeae, Rotylenchulus reniformis, Tylenchorhynchus vulgaris*	Thorne and Schuster (1956); Martin (1959a); Ahmad and Khan (1960); Ayoub (1961); Lal and Yadav (1976)
Trichosanthes dioica Roxb.	*Meloidogyne incognita, Rotylenchulus reniformis*	Mukherji and Sharma (1973); Nath *et al.* (1969)
Trigonella foenum graecum	*Hoplolaimus* sp., *H. indicus, Heterodera* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Rotylenchulus reniformis, Tylenchorhynchus vulgaris*	Bessey (1911); Minz and Solel (1959); Chandwani and Reddy (1967); Krishnamurthy and Elias (1967); Mathur *et al.* (1969); Khan and Khan (1972); Rashid *et al.* (1973); Khan (1975)
Uraria picta (Jacq.) Desv. Ex. Dc.	*Meloidogyne incognita, M. javanica, Tylenchorhynchus vulgaris*	Haseeb and Pandey (1987)
Woodfordia fruticosa L. Kurz.	*Helicotylenchus* sp., *Longidorus* sp., *Meloidogyne incognita, M. javanica, Tylenchus* sp., *Tylenchorhynchus vulgaris*	Haseeb and Pandey (1987)
Zingiber officinale Rosc.	*Hemicycliophora* sp., *Meloidogyne arenaria, M. incognita, M. incognita acrita, M. javanica, Pratylenchus coffeae, P. pratensis, P. zeae, Radopholus similis, Rotylenchulus reniformis, Xiphinema basiri*	Nagakura (1930); Gadd (1939); Colbran (1958); Goodey *et al.* (1959); Hunt (1959); Mumford (1963); Nadakal (1963); Swarup *et al.* (1967); Upadhyay and Swarup (1972); Koshy and Sosamma (1975); Roy (1973); Sundaraju *et al.* (1979)

References

Acharya, A.; Padhi, N. N.; Swain, P. K. and S. C. Dash. 1988. Occurrence of nematodes on betelvine in Orissa. *Indian J. Nematol.* **18**: 363.

Acosta, N. and A. Ayala. 1975. Pathogenicity of *Pratylenchus coffeae*, *Scutellonema bradys*, *Meloidogyne incognita* and *Rotylenchulus reniformis* on *Dioscorea rotundata*. *J. Nematol.* **7**: 16.

Ahmad, A. and A. M. Khan. 1960. Further studies on the susceptibility of common weeds to the root-knot nematodes, *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949. *Proc. 47th Ind. Sci. Cong.* (Abstr.) 29 p.

Alam, M. M. 1981. Some addition to the host of root-knot nematodes. *Indian Phytopath.* **34**: 243.

Alam, M. M. and A. M. Khan. 1975. Some new host records of the root-knot nematodes in North India. *Indian Phytopath.* **28**: 540-541.

Alam, M. M.; Khan, A. M. and Saxena, S. K. 1973. Some new host records of root-knot nematode, *Meloidogyne incognita* (Kofoid and White, 1919), Chitwood, 1949. *Indian J. Nematol.* **3**: 159-160.

Alam, M. M.; Khan, A. M. and Saxena, S. K. 1976. Additional host records of the root-knot nematode, *Meloidogyne incognita* in North India. *Curr. Sci.* **45**: 350.

Andrassy, I. 1958. *Hoplolaimus tylenchiformis* Daday, 1905 (Syn. *H. coronatus* Cobb, 1923) und die Gottungen der unterfamilie Hoplolaiminae Filipjev 1936, *Nematologica.* **3**: 44-46.

Anonymous. 1966. Annual Report of Betelvine Research Station, Cuddopab, Andhra Pradesh.

Anonymous. 1984. Annual Report 1983-84 Central Institute of Medicinal and Aromatic Plants, Lucknow, India.

Anonymous. 1985. Annual Report 1984-85 Central Institute of Medicinal and Aromatic Plants, Lucknow, India.

Anonymous. 1986. Annual Report 1985-86 Central Institute of Medicinal and Aromatic Plants, Lucknow, India.

Anonymous. 1987a. Annual Report 1986-87 Central Institute of Medicinal and Aromatic Plants, Lucknow, India.

Anonymous. 1987b. Bureau of Nematology, Triology Technical Report, USA, Florida Department of Agriculture and Consumer Service. **26** (2): 7.

Anonymous. 1987c. Bureau of Nematology, Triology Technical Report, USA, Florida Department of Agriculture and Consumer Service. **26** (4): 5-6.

Anonymous. 1988. Annual Report 1987-88 Central Institute of Medicinal and Aromatic Plants, Lucknow, India.

Arumugam, R. and N. Kumar. 1979. Geranium cultivation in Kodaikanal hills. *Indian Perfumer.* **23**: 128-130.

Atkinson, G. F. 1889. A preliminary report upon the life history and metamorphosis of a root gall nematode, *Heterodera radicicola* (Greeff) Muhland the injuries causes by it to the roots of various plants. *Bull. Ara. Polytech. Inst. n.s.* 19.

Atu, U. G.; Odurukwe, S. O. and R. O. Ogbuji. 1983. Root-knot nematode damage to *Dioscorea rotundata. Plant Dis.* **67**: 814-815.

Atwal, A. S. and A. Mangar. 1971. Biology, host range and abundance of *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949. *J. Zool. Soc. India.* **23**: 113-118.

Ayala, A. 1966a. Annual report of the department of Entomology, Agric. Exp. Stn. Rio Piedras PR.

Ayala, A. 1966b. Nematode problems in Puerto Rican Agriculture. *Proc. Symp. Trop. Nematol. Univ.* PR . Agric. Exp. Stn. Rio Piedras Puerto Rico. pp 135-145.

Ayala, A. and N. Acosta. 1971. Observations on yam (*Dioscorea alata*) nematodes. *Nematropica.* **1**: 39-40.

Ayoub, S. M. 1961. *Pratylenchus zeae* found upon corn, milo and three suspected new hosts in California. *Pl. Dis Reptr.* **45**: 940.

Ayyar, P. K. K. 1933. Further experiments on the root-gall nematode, *Heterodera marioni* (Cornu) Goodey in South India. *Indian J. Agric. Sci.* **3**: 1064-1071.

Azmi, M. I. 1978. Nematodes of silivipastrol system II. Studies on *Helicotylenchus dihystera. Indian J. Nematol.* **8**: 151-153.

Baker, A. D. 1959. Some records of plant parasitic nematodes encountered in Canada, in 1958. *Can. Insect Pest Rev.* **37**: 120-122.

Balasubramanian, M. and G. Rangaswami. 1964. Studies on host range and histopathology of root-knot infections caused by *Meloidogyne javanica. Indian Phytopath.* **17**: 126-132.

Barnes, R. F. and S. R. Gowen. 1969. "Root-knot nematodes in Trinidad." In: *Nematodes of tropical crops* (ed. Peachey, J. E.) Commonwealth Bur Helminthol Tech Comm 40, St Albans, Herts, England, pp. 155-161.

Basu, S. D. and B. Banerjee. 1978. Effect of infestation of *Meloidogyne incognita* (Kofoid and White) Chitwood on some ancillary plants grown with tea in North East India. *Two and A bud* **25**: 28-29.

Baudys, E. 1948. Sedmy prispevek k zooceicidiologickemu prozokoumani Moravy a Sleska. Sb. Vys. Sk. Zemed. Brne. No. C43, p. 64.

Bergeson, G. B. 1963. Influence of *Pratylenchus penetrans* alone and in combination with *Verticillium albo-atrum* on growth of peppermint. *Phytopathology.* **53**: 1164-1166.

Bergeson, G. B. and R. J. Jr Green. 1979. Damage to cultivars of peppermint, *Mentha piperita*, by the lesion nematode, *Pratylenchus penetrans. Indian J. Nematol.* **7**: 154.

Bessey, E. A. 1911. Root-knot and its control. *Bull. Bur. Plant Indust.* USDA, **217**: 89.

Bhatti, D. S. and R. S. Dahiya. 1977. New host records of *Meloidogyne* spp. *Indian J. Nematol.* **7**: 154.

Bhatti, D. S.; Gupta, D. C.; Dahiya, R. S. and I. Malham. 1974. Additional hosts of the root-knot nematodes, *Meloidogyne javanica. Curr. Sci.* **43**: 622-623.

Birchfield, W. 1956. New and suspected host plant of burrowing nematode, *Radopholus similis* (Cobb) Thorne. *Pl. Dis. Reptr.* **40**: 866-868.

Blake, C. D. 1963. Identification and distribution of root-knot nematodes (*Meloidogyne* spp.) in New South Wales with special reference to the Richmond Tweed region. *Proc. Linn. Soc. NSW.* **88**: 373-378.

Bos, J. Ritzema. 1903. Dri bit jetzt unbekannte von *Tylenchus devastatrix* verursachte Pflanzenkrankheiten. *Z. Pflkrankh. Pflpath. Pflschutz.* **13**: 193-198.

Bos, W. S. 1978. Root-knot nematodes in the Nigerian Savana Zones with special reference to root-knot problems of irrigated crops in the Kano River Project at Kadawa. *Proc. of the Second Res. Plann. Conf. On Root-knot nematodes, Meloidogyne spp. Region IV*, Abidjan, Ivory Coast, p. 93.

Breda De Haan, J. Van. 1899. Levensgeschiedenis en besttrijding van het tabaksaaltje (*Heterodera radicicola*) in deli. Memed. Lds. Pltuin. Batavia. p. 35.

Brooks, T. L. 1954. Host range of burrowing nematode internationally and in Florida. *Citrus Indust.* **35**: 7-8, 14.

Brooks, T. L. 1955. Additional host of the burrowing nematode in Florida. *Pl. Dis. Reptr.* **39**: 309.

Buhrer, E. M. 1938. Additions to the list of plants attacked by the root-knot nematode (*Heterodera marioni*). *Pl. Dis. Reptr.* **22**: 216-234.

Buhrer, E. M.; Cooper, C. and G. Steiner. 1933. A list of plants attacked by the root-knot nematode (*Heterodera marioni*). *Pl. Dis. Reptr.* **17**: 64-96.

Butool, F. and A. Haseeb. 1992. Relationship between root-knot nematode, *Meloidogyne incognita* and growth/yield of *Trachyspermum ammi. Curr. Nematol.* **3**: 35-38.

Butool, F. and A. Haseeb. 1996. Influence of *Glomus aggregatum* on root-knot development caused by *Meloidogyne incognita* in *Hyoscyamus muticus. Afro-Asian J. Nematol.* **6**: 188-190.

Butool, F.; Haseeb, A. and P. K. Shukla. 1998. Management of root-knot nematode, *Meloidogyne incognita*, infesting Egyptian Henbane, *Hyoscyamus muticus* L. by the use of nematicides and oil cakes. *Int. J. Pest Manag.* **44**: 199-202.

Caveness, F. E. 1979. "Cowpea, lima bean, cassava, yams and *Meloidogyne* spp. in Nigeria." In: *Root-knot nematode (Meloidogyne species): systematics, biology and control* (eds. Lamberti, F. and C. E.Taylor) Academic Press, London, pp. 295-300.

Chandrasekaran, N. M. 1964. Studies on the reniform nematode, *Rotylenchulus reniformis* (Linford and Oliviera, 1940) with special reference to its pathogenicity on castor (*Ricinus communis* Linn.) and ragi (*Eluecine corcana* Gaertn.). *Madras Agric. J.* **51**: 443.

Chandwani, G. H. and T. S. N. Reddy. 1967. The host range of root-knot nematode *Meloidogyne javanica* in tobacco nurseries at Rajahmundry, Andhra Pradesh. *Indian Phytopath.* **20**: 383-384.

Chidambaranathan, A. and G. Rangaswamy. 1965. Studies on the pathogenicity and host range of three species of root-knot nematodes. *Indian Phytopath.* **18**: 168-173.

Chitamber, J. A. and P. Gupta. 1977. Some new host records of phytonematodes. *The Allahabad farmer.* **51**: 299-300.

Colbran, R. C. 1958. Studies of plant and soil nematodes. 2. Queensland host records of root-knot nematode (*Meloidogyne* species). *Queensland J. Agric. Sci.* **15**: 101-136.

Dahiya, R. S.; Mangat, B. P. S. and D. S. Bhatti. 1988. Some new host records of *Meloidogyne javanica. Int. Nematol. Netw. Newsl.* **5**: 32-34.

Das, V. M. 1960. Studies on nematode parasites of plants in Hyderabad. *Zeitschriftt. Fur Parasitenkunde.* **19**: 533-605.

Das, V. M. and S. Sultana. 1979. Five new species of genus *Pratylenchus* from vegetable crops of Hyderabad (Andhra Pradesh). *Indian J. Nematol.* **9**: 5-14.

Decker, H. 1968. Phytonematologische untersuchungen in Cuba. *Wissz Univ Rostock, Math-Nat.* **17**: 421-438.

Delacroix, G. 1901-02. Pathologie vegetable maladies vermicularies. I. Sur une maladie vermiculaire das bananiersen Egypte. II. Sur une maladie du poivrier (*Piper nigrum*) en Cochinchine. *Agriculture prat. Pays. Chauds.* **1**: 672-680.

D'Errico, F. P.; Nicotina, M. and A. G. Mahmood. 1991. *Ditylenchus dipsaci* damaging different crops in Salerno. *Informatore Fitopathologica.* **41**: 59-61.

Dhande, G. W. and M. Sulaiman. 1961. Occurrence of root-knot nematodes betelvine in Maharashtra. *Curr. Sci.* **30**: 351-352.

Dixon, W. B. and R. Latta. 1965. Nematological investigations 1958-1961. Bull No. 59 (New Series). Min. Agric. and Lands Jamaica. p. 35.

Djiwanti, S. R. and Y. Momota. 1991. Parasitic nematodes associated with patchouli disease in West Java. *Indust. Crop Res. J.* **3**: 31-34.

D'Souza, G. I. and P. R. Kashivishwanathan. 1989. *Cassia tora* L. – a new host of *Pratylenchus coffeae* in South India. *All India Nematol. Symp.*, New Delhi, p. 18.

Edward, E. E. 1955. Further observation of the occurrence of nematodes of the genus *Meloidogyne* in the Cold Coast. *J. Helminthol.* **29**: 153-170.

Edward, J. C.; Mishra, S. L.; Peter, E. and B. B. Rai. 1971. A new species of *Criconema* associated with pomegranate (*Punica granatum* L.). *Indian J. Nematol.* **1**: 59-62.

Ekundayo, J. A. and S. H. Z., Naqvi. 1972. Preharvest rotting of yams (*Dioscorea* spp.) in Nigeria. *Trans. British Mycol. Soc.* **58**: 15-18.

Esmenjaud, D.; Minot, J. C.; Voisin, R. and de G. Guiran. 1990. *Pratylenchoides laticauda* on peppermint in Southern alps, host range, population densities in different crop relations and host suitability of three mint subspecies. *Meded Van de Facult. Land Rijksun Gent.* **55**: 779-786.

Fajardo, T. G. and M. A. Palo. 1933. The root-knot nematode, *Heterodera radicicola* (Greeff) Muller of tomato and other plants in the Phillippines Island. *Phillippines J. Sci.* **51**: 457-484.

Faulkner, L. R. 1962. Pathogenicity and population dynamics of *Pratylenchus hamatus* Thorne and Allen, on *Mentha* spp. *Phytopathology.* **52**: 731.

Faulkner, L. R. 1964. Pathogenicity and population dynamics of *Pratylenchus hamatus* on *Mentha* spp. *Phytopathology.* **54**: 344-348.

Faulkner, L. R. and W. J. Bolander. 1969. Interaction of *Verticillium dehliae* and *Pratylenchus minyus* in *Verticillium* wilt of peppermint: Effects of soil temperature. *Phytopathology.* **59**: 868-870.

Faulkner, L. R. and C. B. Skotland. 1963. Control of *Verticillium* wilt of mint and plant parasitic nematodes associatd with mint by soil fumigation. *Pl. Dis. Reptr.* **47**: 662-665.

Faulkner, L. R. and C. B. Skotland. 1965. Interactions of *Verticillium dehliae* and *Pratylenchus minyus* in *Verticillium* wilt of peppermint. *Phytopathology.* **55**: 583-586.

Fluiter, H. J., De and J. J. Mullholland. 1941. Gegevens verkregen bij het onderzoek near de waardplanten van *Tylenchus coffeae. Bergcultures.* **15**: 1588-1593.

Franklin, M. T. 1940. On the identification of the strains of *Heterodera schachtii. J. Helminthol.* **18**: 63-84.

Franklin, M. T. 1945. On the *Heterodera* cruciferae n. sp. of Brassica and on a *Heterodera* strain infecting clover and dock. *J. Helminthol.* **21**: 71-84.

Franklin, M. T. 1959. *Nacobbus serendipiticus* n. sp. a root galling nematode from tomatoes in England. *Nematologica.* **4**: 286-293.

Gadd, C. H. 1939. A destructive root disease of tea caused by the nematode *Anguillulina pratensis. Tea Q.* **12**: 131-139.

Gaskin, T. A. 1958. Weed hosts of *Meloidogyne incognita* in Indiana. *Pl. Dis. Reptr.* **42**: 802-803.

Gaskin, T. A. and H. W. Crittenden. 1956. Studies of the host range of *Meloidogyne hapla. Pl. Dis. Reptr.* **40**: 265-270.

Geisenheyner, L. 1902. Uber enige neue und seltenere zoocecidien aus dem nehegebiete. *Allg. Z. Entom.* **7**: 193, 198, 246-251, 272-276, 303-312.

Georghiou, G. P. 1957. Records and notes on the plant parasitic nematodes of Cyperus. *Tech. Bull. Cyprus, Dept. Agric.* TB-3, p. 5.

Gillard, A. and J. Van den Brande. 1956. Bijdrage tot de studie de waardplanten van de worteelknobbelaaltjes *Meloidogyne hapla* Chiwood on *Meloidogyne arenaria* Neal. *Meded. Landbhoogesch. Opzoelstns. Gent.* **21**: 653-662.

Goffart, H. 1931. Beobachtungen uber Pflanzenschadliche Nematoden an Fartenpflanzen. *Gartenbauwiss.* **5**: 353-359.

Goffart, H. 1951. *Nematoden der kulturepflanzen Europas*. Berlin P. Parey, p. 144.

Goffart, H. 1953. Beobachtungen an pflanzenschaidlichen nematodes 1. *Nachr Bl. Dt. Pflschutzdienst Stutt.* **5**: 150-153.

Goffart, H. 1957. Bemerkungen zu enigen arten der Gattung *Meloidogyne. Nematologica.* **2**: 177-184.

Gokte, N. and V. K. Mathur. 1990. Thermal therapy for the eradication of *Mentha spicată* roots infected with *Meloidogyne incognita. FAO Plant Prot. Bul.* **8**: 213-215.

Goodey, T. 1940. *The nematode parasites of plants catalogued under their hosts*. Imp. Bur. Agric. Parasit. (Helminth.), St. Albans, England, p. 80.

Goodey, G. B. 1952. Investigations in to the host ranges of *Ditylenchus destructer* and *D. dipsaci. Ann. Appl. Biol.* **39**: 221-228.

Goodey, J. B.; Franklin, M. T. and D. J. Hooper. 1959. Supplement to the nematode parasites of plants catalogued under their host 1955-1958. *Farnham Royal England, Common Agric. Bur.* p. 66.

Goodey, J. B.; Franklin, M. T. and D. J. Hooper. 1965. *T. Goodey's the nematode parasites of plants catalogued under their hosts.* III ed. Commonw. Agric. Bur. Far., Royal, England, p. 214.

Goodey, T.; Goodey, J. B. and M. T. Franklin. 1956. The nematode parasites of plants catalogued under their hosts. Revised edition of T. Goodey, 1940, Farnham Royal England, *Common Agric. Bur.* p. 140.

Gram, E. and S. Rostrup. 1924. Root-knot on Sambucus nigra. *Tidsskr. Pla. vl.* **30**: 392.

Greco, N.; Vito Di. M.; Saxena, M. C. and M. V. Reddy. 1988. Investigation on the root lesion nematode, *Pratylenchus thornei* in Syria. *Nematol. Medit.* **16**: 101-105.

Gundy, S. D. Van and R. L. Rackham. 1961. Studies on the biology and pathogenicity of *Hemicycliophora arenaria. Phytopath.* **51**: 393-397.

Gundy, S. D. Van; Thomason, I. J. and R. L. Racham. 1959. The reaction of three citrus spp. to three *Meloidogyne* spp. *Pl. Dis. Reptr.* **43**: 970-971.

Gupta, D. C. and M. R. Dalal. 1973. *Meloidogyne javanica* associated with Kadam (*Anthocephalus cadamba* Roxb.). *Pesticides.* **7**: 29.

Gupta, N. K. and Uma. 1980. *Quinisulcius punici* (*Tylenchorhynchidae : Tylenchida*) a new species from India. *Proc. Indian Acad. Sci.* **89**: 415-418.

Harris, W. V. 1938. Root-knot Eelworm. *E. Afri. Agric. J.* **4**: 25-30.

Haseeb, A. 1992. "Nematode pests of medicinal and aromatic plants." In: *Nematode Pests of Crops* (eds. Bhatti, D. S. and R. K. Walia) CBS Publication, New Delhi, India, pp. 239-249.

Haseeb, A. 1993. Studies on certain aspects of pathogenicity of *Pratylenchus thornei* on mint and its control. Final Technical Report – An ICAR, New Delhi, India sponsored project (F. No. 2-5/88 PP dt. 29.03.1989).

Haseeb, A. 1994. "Plant parasitic nematodes of medicinal and aromatic plants." In: *Vistas in Seed Biology* (eds. Singh, T. and P. C. Trivedi) Printwell Publication, Jaipur, India, pp. 98-119.

Haseeb, A. 1996. Studies on nematode diseases of *Ocimum* species and its control. Final Technical Report – An ICAR, New Delhi, India sponsored project (F. No. 2 (8)/91-PP dt. 09.06.1993).

Haseeb, A. and F. Butool. 1989. Pathogenicity and reproduction of *Meloidogyne incognita* on *Ocimum sanctum. Int. Nematol. Network Newsl.* **6**: 27-30.

Haseeb, A. and F. Butool. 1991. Evaluation of different pesticides and oil cake on the control of root-knot nematode (*Meloidogyne incognita*) infecting Davana (*Artemissia pallens*). *Curr. Nematol.* **2**: 204-210.

Haseeb, A. and F. Butool. 1993. Use of some pesticides and oil seed cakes for the control of *Meloidogyne incognita* on *Trachyspermum ammi. Afro-Asian J. Nematol.* **3**: 112-114.

Haseeb, A.; Butool, F. and R. Pandey. 1988a. Effect of different inoculum levels of root-knot nematode, *Meloidogyne incognita* on the root-knot development, growth and oil yield of *Ocimum basilicum. Proc. Symp. Recent Advanc. Physiol. Plant Path.* p 70.

Haseeb, A.; Butool, F. and R. Pandey. 1988b. Influence of different initial population densities of *Meloidogyne incognita* on the growth and oil yield of *Ocimum basilicum* cv. French. *Indian J. Plant Path.* **6**: 176-179.

Haseeb, A.; Butool, F. and P. K. Shukla. 1996.Relationship between different initial inoculum densities of *Meloidogyne incognita* and plant growth, oil yield, physiological/biochemical changes in plants of *Ocimum canum. Nematropica.* **26**: 181-185.

Haseeb, A.; Butool, F. and P. K. Shukla. 1998a. Relationship between various initial inoculum densities of *Meloidogyne incognita* and growth, physiology and oil yield of *Ocimum kilmandscharicum. Nematol. Medit.* **26**: 19-22.

Haseeb, A.; Butool, F. and P. K. Shukla. 1999c. Effect of *Meloidogyne incognita* on growth, physiology and oil yield of *Ocimum sanctum. Indian J. Nematol.* **29**: 121-125.

Haseeb, A.; Butool, F. and P. K. Shukla. 2000a. Influence of *Pratylenchus thornei* and *Meloidogyne incognita* alone and in combination on growth of *Hyoscyamus niger. Indian J. Nematol.* **30**: 165-169.

Haseeb, A.; Butool, F. and P. K. Shukla. 2000c. Effect of different initial inoculum densities of *Meloidogyne incognita* on the growth and herb yield of *Coleus forskohlii. Proc. 2nd Indian Agric. Scientists and Farmers Cong.* held at Allahabad University, Allahabad during 19th – 20th February, 2000, pp. 15.

Haseeb, A. and R. Pandey. 1987. Incidence of root-knot nematodes in medicinal and aromatic plants-new host records. *Nematropica.* **17**: 209-212.

Haseeb, A. and R. Pandey. 1989a. Root-knot disease of Henbane, *Hyoscyamus* – a new disease record. *Tropical Pest Manag.* **35**: 212-213.

Haseeb, A. and R. Pandey. 1989b. Observations on *Meloidogyne* species affecting Japanese mint – new disease record. *Nematropica.* **19**: 93-97.

Haseeb, A. and R. Pandey. 1989c. Root-knot nematode – A constraint to cultivation of Davana, *Artemissia pallens. Trop. Pest Manag.* **35**: 317-319.

Haseeb, A.; Pandey, R. and F. Butool. 1987. Plant parasitic nematodes associated with some medicinal and aromatic plants. *Proc. 57th Ann. Sess. Nat. Acad. Sci.* India. p 40.

Haseeb, A.; Pandey, R. and A. Husain. 1984. Some new host records of the root-knot nematode, *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949. *Curr. Sci.* **53**: 1151-1152.

Haseeb, A.; Pandey, R. and A. Husain. 1985. New host records of the root-knot nematode, *Meloidogyne javanica. FAO Plant Protec. Bull.* **33**: 123.

Haseeb, A.; Pandey, R. and A. Husain. 1986a. Studies on nematode disease of *Ocimum* species. *Proc. 56th Ann. Sess. Nat. Acad. Sci.* India, pp76.

Haseeb, A.; Pandey, R. and A. Husain. 1986b. Pathogenicity of root-knot nematode, *Meloidogyne incognita* on Davana, *Artemissia pallens. Proc. Nat. Conf. Plant Parasitic Nemat. India Prob. and Progress*, pp. 21-22.

Haseeb, A.; Pandey, R. and A. Husain. 1988c. A comparison of nematicides and oil seed cakes for control of *Meloidogyne incognita* on *Ocimum basilicum. Nematropica.* **18**: 65-69.

Haseeb, A. and A. Sharma. 2005. Management of *Meloidogyne incognita – Sclerotinia sclerotiorum* disease complex on *Mentha arvensis* cv. Gomti through chemicals, organic amendments and bioagents. *Proc. Nat. Symp. Recent advances and Research Priorities in Indian Nematology*, held at IARI, New Delhi, during 9th – 10th Decemberber, 2005, p. 6.

Haseeb, A.; Sharma, A. and S. Abuzar. 2005. Studies on the management of *Meloidogyne incognita* on *Mentha arvensis* cv. Gomti by application of bio-agents, chemicals and organic amendments under pot conditions. *Proc. 6th Nat. Symp. Sustainable Plant Protection Strategies: Health and Environmental Concerns*, held at Ratnagiri on 15th – 17th October, 2005. p. 118.

Haseeb, A. and P. K. Shukla. 1994a. Studies on vertical distribution of plant parasitic nematodes associated with *Mentha piperita* L. *Proc. II Afro-Asian Nematol. Symp.*, Menofiya, Cairo, Egypt, pp. 121-124.

Haseeb, A. and P. K. Shukla. 1994b. Effect of *Pratylenchus thornei* on growth, physiology and oil yield of *Mentha spicata. Afro-Asian J. Nematol.* **4**: 51-53.

Haseeb, A. and P. K. Shukla. 1995. Influence of *Pratylenchus thornei* on growth, photosynthetic rate, chlorophyll, total sugar and oil yield of *Mentha citrata. Nematol. Medit.* **23**: 89-91.

Haseeb, A. and P. K. Shukla. 1996. Suppressive effect of *Pratylenchus thornei* on the growth, oil yield, physiological and biochemical parameters of *Mentha piperita. Nematropica.* **26**: 81-85.

Haseeb, A. and P. K. Shukla. 2000a. "Nematode diseases of mints and their control." In: *Advances in Plant Disease Management* (eds. Narain, U.; Kumar, K. and M. Srivastava) Advance Publishing Concept, New Delhi, pp. 229-248.

Haseeb, A. and P. K. Shukla. 2001. "Nematode diseases of Mentha and their management." In: *Role of Resistance in Intensive Agriculture* (eds. Nagarajan, S. and D. P. Singh) Kalyani Pub., Ludhiana, India, pp. 60-77.

Haseeb, A.; Shukla, P. K. and F. Butool. 1993a. Relationship between different initial inoculum densities of *Meloidogyne incognita* and growth/oil yield of Indian basil. *Indian J. Plant Pathol.* **11**: 53-56.

Haseeb, A.; Shukla, P. K. and F. Butool. 1998b. Influence of hydro-distillation wastes of medicinal plants, oil cakes and pesticides on *Meloidogyne incognita* infesting *Ocimum canum. Curr. Nematol.* **9**: 5-13.

Haseeb, A.; Shukla, P. K. and F. Butool. 1998c. Effects of carbofuran and neem cake on root-knot disease of Ocimum kilmandscharicum. *Proc. Nat. Sem. on Bio-inoculants for sustainable Development* held at Gurukul Kangri Vishwa Vidyalaya, Haridwar, during 23rd-25th September, 1998.

Haseeb, A.; Shukla, P. K. and F. Butool. 1999a. Effect of different pH levels and plant parasitic nematodes on the germination, survival and growth of *Hyoscyamus niger. Proc. Third Internat. Symp. Afro-Asian Soc. Nematologists on Nematology: Challenges and Opportunities in 21st century* held at Sugarcane Breeding Institute, Coimbatore during 16th - 19th April, 1998, pp. 45-50.

Haseeb, A.; Shukla, P. K. and F. Butool. 1999b. Effect of different soil types on the growth and oil yield of *Ocimum canum* and reproduction of *Meloidogyne incognita. Proc. Third Internat. Symp. Afro-Asian Soc. Nematologists on Nematology: Challenges and Opportunities in 21st century* held at Sugarcane Breeding Institute, Coimbatore during 16th-19th April, 1998, pp. 39-47.

Haseeb, A.; Shukla, P. K. and F. Butool. 2000b. Relationship between pH levels, *Meloidogyne incognita* and plant growth and oil yield of *O. canum. Indian J. Nematol.* **30**: 129-132.

Haseeb, A.; Srivastava, N. K. and F. Butool. 1993b. Effect of *Meloidogyne incognita* on the growth, physiology, nutrient concentration and alkaloid yield of *Hyoscyamus albus. Afro-Asian J. Nematol.* **3**: 165-169.

Haseeb, A.; Srivastava, N. K. and R. Pandey. 1990. The influence of *Meloidogyne incognita* on the growth, physiology, nutrient concentration and alkaloid yield of *Hyoscyamus niger. Nematol. Medit.* **18**: 127-129.

Hawely, W. O. 1956. Hot water treatment for the control of root-knot nematodes on *Dioscorea floribunda. Pl. Dis. Reptr.* **40**: 1045-1046.

Hollrung, M. 1890. *The testing of agricultural cultivated plants and weeds for their resistance to beet nematode.* Jber. Vernsstn. Pflsch. Halle. p 5.

Horner, C. E. and H. J. Jensen. 1954. Nematodes associated with mints in Oregan. *Pl. Dis. Reptr.* **38**: 39-41.

Hunt, J. 1958. *List of intercepted plant pests*, 1957. ISDA, ARS, Plant Quarnt. Div. p 66.

Hunt, J. 1959. *List of intercepted plant pests*, 1958. USDA, Res. Ser. Plant Qurant. Div. p 85.

Hurst, R. R. 1948. The potato rot nematode, *Ditylenchus destructer* in PEI. *Proc. Canadian Phytopath. Soc.* **15**: 17.

Husain, A. 1983. "Present and future of medicinal plants in India – A scientific appraisal." In: *Report of the Seminar on Medicinal Plants. Phytochemicals and Bulk Drugs*, 23-25 March, New Delhi, pp. 33-46.

Husain, S. I. and A. M. Khan. 1967a. *Paurodontella* n. gen. and three new species of nematode from north India (*Nematoda-Neotylenchidae*). *Nematologica.* **13**: 493-500.

Husain, S. I. and A. M. Khan. 1967b. On the status of the genera of the sub-family *Aphelenchoidae* (Fuchs, 1937) Thorne, 1949 with the description of the six new species of nematodes from India. *Proc. Hel. Soc. Wash.* **32**: 167-174.

Husain, S. I. and A. M. Khan. 1967c. A new subfamily, a new subgenus and eight new species of nematodes from India belonging to superfamily-*Tylenchoidea. Proc. Helminth. Soc. Wash.* **34**: 175-186.

Ingham, R. E.; Newcomb, G. B. and M. A. Morris. 1988. Spring nematicide applications for control of root lesion and pin nematodes of peppermint, 1987. *Fungicide and Nematicide Tests.* **43**: 170.

Inserra, R. N. and H. L. Rhoades. 1989. Some nematode problems of spearmint in Florida. Fla. Dept. Agric. and Consumer Serv. Div. Plant Indust – Nemat. Circ. **167**: 4.

Jack, R. W. 1943. Root-knot nematode research. Report for the year ending 30th June, 1943. Rep. Trelawney Tob. Res. Stn. pp 27-39.

Jagdale, G. B.; Pawar, A. B. and K. B. Darekar. 1986. Nematodes associated with betelvine in Maharashtra State (India). *Int. Nematol. Netw. Newsl.* **3**: 12-14.

Jairajpuri, M. S. 1964. On Pratylenchidae (*Pratylenchoides*) Crenicauda Winslow, 1958 (*Nematoda-Pratylenchinae*) from Srinagar (Kashmir), India. *Curr. Sci.* **33**: 339.

Jairajpuri, M. S. and Siddiqui, A. H. 1963b. On three new species of the genus *Criconemoides*, Taylor, 1936 (*Nematoda-Creconematidae*) from Dalhousie (HP) North India. *Z. Parasitenk.* **23**: 340-347.

Jatala, P. and H. J. Jensen. 1974. Oxamyl controls *Longidorus elongatus* on peppermint in greenhouse experiments. *Pl. Dis. Reptr.* **58**: 591-593.

Jenkins, W. R. and C. W. Bird. 1962. Nematodes associated with wild yam, *Dioscorea* sp. with special reference to the pathogenicity of *Meloidogyne incognita. Pl. Dis. Reptr.* **46**: 858-860.

Jensen, H. J. 1953. Experimental green house host range studies of two root lesion nematode, *Pratylenchus vulnus* and *P. penetrans. Pl. Dis. Reptr.* **37**: 384-387.

Jensen, H. J. and Horner, C. E. 1956. A decline of peppermint caused by an ectoparasitic nematode, *Longidorus sylphus. Phytopathology.* **46**: 637.

Jones, F. G. W. 1950. Observations of beet eelworm and other cyst forming species of *Heterodera. Ann. Appl. Biol.* **37**: 407-440.

Junges, W. 1938. Systematik und variabilitat der pflanzenparasitichen Aphelenchen spwie deren Verbreitung an versichiedenen wirtspflanzen. *Z. Parasitikda* **10**: 559-607.

Kelenyi, G. P. 1949. Practices adopted in the experimental culture of *Duboisia* spp. Divl. Rep. CVSIRO, Div. Plant Indus No. 4.

Khan, F. A. 1975. Some new host records of the reniform nematode in India. *Indian Phytopath.* **28**: 386-387.

Khan, A. M. and Alam, M. M. 1974. Incidence of the root-knot nematode, *Meloidogyne javanica* (Treub, 1885), Chitwood, 1949 in certain wild and cultivated plants with some new host records. *Geobios.* **1**: 146-147.

Khan, E.; Chawla, M. L. and M. Saha. 1975. *Creconematoidea* (*Nematoda-Tylenchida*) from India with description of nine new species, two new genera and a family. *Indian J. Nematol.* **5**: 70-100.

Khan, F. A. and A. M. Khan. 1972. Studies on the distribution and population of *Longidorus brevicaudatus, Xiphinema basiri* and *X. americanum* in Uttar Pradesh and Rajasthan with description of *Longidorus psidii* n. sp. (*Nematoda-Dorlaimoidea*). *Indian Phytopath.* **25**: 264-269.

Khan, F. A. and A. M. Khan. 1973. Studies on the reniform nematode, *Rotylenchulus reniformis* I. Host range and population changes. *Indian J. Nematol.* **3**: 24-30.

Khan, E. and C. K. Nanjappa. 1972. Four new species of *Creconematoides* (Nematoda) from India. *Indian J. Nematol.* **2**: 59-68.

Khan, A. M.; Siddiqui, M. R.; Khan, E.; Husain, S. I. and S. K. Saxena. 1964. *List of stylet forming nematodes reported from India.* Nematol. Pub. No. 1, AMU, Aligarh, India.

Kirijanova, E. S. 1939. "The stem nematode as a pest of agricultural crops in the USSR." In: *Collected works on nematodes of agricultural crops.* (eds. Kirijanova, E. S.) Moscow and Leningrade Sel 'Khogiz, p 247.

Kir'yanova, E. S. and E. L. Krall. 1980. *Plant parasitic nematodes and their control.* Volume II, Amerind Publ. Co. Pvt. Ltd., New Delhi, pp 748.

Koshy, P. K. and V. K. Sosamma. 1975. Host range of burrowing nematode, *Radopholus similis* (Cobb, 1913) Thorne, 1949. *Indian J. Nematol.* **5**: 252-257.

Koshy, P. K.; Sosamma, V. K. and Sundaraju, P. 1977. Screening of plants used as pepper standards against root-knot nematode. *Indian Phytopath.* **30**: 128-129.

Koshy, P. K. and G. Swarup. 1972. Susceptibility of plants to pegion pea cyst nematode, *Heterodera cajani. Indian J. Nematol.* **2**: 1-6.

Krishnamurthy, G. V. G. and N. A. Elias. 1967. Host-range of *Meloidogyne incognita* causing root-knot on tobacco in Hunsur, Mysore State. *Indian Phytopath.* **20**: 374-377.

Krishnaprasad, P. R. and D. D. R. Reddy. 1979. Study on the root-knot nematode infecting patchouli (*Pogostemon cablin*, Benth.). *Mysore J. Agric. Sci.* **13**: 367-368.

Kuhn, J. 1881. Die Ergebnisse der versuche zur ermittlung der ursache der rubernmudigkeit und zur erforschung der nature der nematoden. *Ber. Physiol. Lab. Landw. Inst. Univ. Halle.* **3**: 1-153.

Kuhn, J. 1959. Zur kenntnis der wirtspflanzen von Ditylenchus destructor, Thorne, 1945. Nachr. Bl. Dt. Pflanzenschutzdienst Berlin, **13**: 57-58.

Kumar, S. and K. Nanjan. 1983-84. Control of spiral nematodes in patchouli. Fungicide and nematicide tests. *Ameri. Phytopath. Soc.* **39**: 93.

Kumar, S. and K. Nanjan. 1985. Increasing Geranium yield. *Indian Perfumer.* **29**: 121-124.

Lal, B. S. and M. N. A. Ansari. 1960. Field studies on the root-knot nematodes (*Meloidogyne* spp.) (*Nematoda:Heteroderidae*). *Sci. and Cult.* **26**: 279-281.

Lal, R.; Nagarajan, K. and G. V. G. Krishnamurthy. 1976. Weed host of root-knot nematode (*Meloidogyne javanica*) in tobacco nurseries. *Ind. Tobacco Bull.* **8**: 3-5.

Lal, R.; Nagarajan, K. and G. V. G. Krishnamurthy. 1977. Additional weed hosts of root-knot nematode (*Meloidogyne javanica*) in tobacco nurseries. *Ind. Tobacco Bull.* **9**: 3-4.

Lal, A. and B. S. Yadav. 1976. Effect of soil salinity on the occurrence of phytoparasitic nematodes. *Indian J. Mycol. Pl. Pathol.* **16**: 82-83.

Lamberti, F.; Rohini, H. M. and K. Ekanayake. 1983. Effect of some plant parasitic nematodes on the growth of black pepper in Sri Lanka. *Plant Protect. Bull.* **31**: 163-166.

Landhardt, K. 1963. Rodal (*Meloidogyne hapla*, Chitwood, 1949) pa friland. *Tidskr. Pl. Avl.* **67**: 676-687.

Licopoli, L. 1877. *Le galle nella flora di alcune provincie napolitane*. Napoli, p 64.

Linde, W. J. Van der. 1956. *The Meloidogyne* problem in South Africa. *Nematologica* **1**: 177-183.

Linde, W. J. Van Der; Clemitson, J. G. and M. E. Crous. 1959. Host parasite relationships of South African root eelworm (*Meloidogyne* spp.). *Sci. Bull. Dep. Agric. Tech. Serv. Un. S. Africa.* **385**: 1-6.

Linford, M. B. and F. Yap. 1940. Some host plant of the reniform nematode in Hawaii. *Proc. Helmint. Soc. Wash.* **7**: 42-44.

Loof, P. A. A. 1960. Taxonomic studies on the genus *Pratylenchus* (Nematoda). *Tijdschr. PLZiekt.* **66**: 29-90.

Lordello, L. G. E. 1957. Galhas gigantes em raizes de Clitoria ternatea. *Chacaras Quint.* **96**: 200.

Luc, M. and G. De Guiran. 1960. Les nematodes associes aux plantes de Louest Africain. Liste preliminaire. *Agron. Trop. Nogent.* **15**: 434-449.

Machmer, J. H. 1951. Root-knot of peanut. 1. Distribution. *Pl. Dis. Reptr.* **35**: 364-366.

Maggenti, A. R. and W. H. Hart. 1963. Control of root-knot nematodes on hops. *Pl. Dis. Reptr.* **47**: 883-885.

Mai, W. F.; Crittenden, H. W. and W. R. Jenkins. 1960. Distribution of stylet bearing nematodes in north eastern United States. *Bull. New Jers. Agric. Exp. Stn.* 795, p 62.

Mammen, K. V. 1974. On a wilt disease of betelvine in Kerala caused by root-knot nematode. *Agr. Res. J. Kerala.* **12**: 76.

Maqbool, M. A.; Hashmi, S. and A. Ghaffar. 1985. New host record of root-knot nematodes (*Meloidogyne* spp.) in Pakistan and identification of physiological races. *Pak. J. Nematol.* **3**: 49-52.

Martin, G. C. 1954. Nematodes. *Rhod. Tob. J.* **6**: 65-70.

Martin, G. C. 1958. Root-knot nematodes *Meloidogyne* spp. in the Federation of Rhodesia and Nyasaland. *Nematologica.* **3**: 332-349.

Martin, G. C. 1959. The common root-knot nematode. *Rhod. Farmer.* **27**: 24-26.

Martin, G. C. 1961. Plant species attacked by root-knot nematodes (*Meloidogyne* spp.) in the Federation of Rhodesia and Nyasaland. *Nematologica.* **6**: 130-134.

Mathur, V. K.; Lal, A.; Sanwal, K. C. and R. V. Singh. 1980. Record of plant parasitic nematodes on *Glycyrrhiza glabra. Indian J. Nematol.* **10**: 257-258.

Mathur, R. L.; Mathur, B. N. and D. K. Handa. 1969. Additions to host records of root-knot nematodes. *Nematologica.* **15**: 160-161.

McBride, J. M.; Johns, D. M. and C. R. Carter. 1961. Relative host responses of interplanted weeds and corn to *Pratylenchus zeae* and *P. brachyurus* (*Nematoda-Tylenchida*). *Phytopathology.* **51**: 644.

McMillen, H. G. 1941. Some diseases of drug plants and herbs observed in the southern California *Pl. Dis. Reptr.* **25**: 443-445.

Minz, G. 1943 Additinal list of plants attacked by *Heterodera marioni. Hassadeh.* **24**: 104.

Minz, G. 1956. The root-knot nematode, *Meloidogyne* spp., in Israel. *Pl. Dis. Reptr.* **40**: 798-801.

Minz, G. 1958. Root-knot nematodes, *Meloidogyne* sp. in Israel. *Spl. Bull. Agric. Res. Stn. Rehovor.* **12**: 10

Minz, G. 1963. Additional hosts of the root-knot nematode, *Meloidogyne* spp., recorded in Israel during 1960-1962. *Israel J. Agric. Res.* **13**: 133-134.

Minz, G. and Z. Solel. 1959. New records of crop diseases in Israel. *Pl. Dis. Reptr.* **43**: 1051.

Mohandas, C. 1975. *Helicotylenchus trivandranus* sp. n. (*Nematoda-Haplolaimidae*) from Kerala in India. *Indian J. Nematol.* **5**: 105-107.

Mohandas, C.; Ramana, K. V. and D. J. Raski. 1985. *Trophotylenchulus piperis* n. sp. parasitic on *Piper nigrum* L. in Kerala, India (Nematoda: Tylenchulidae). *Revue de Nematologie.* **8**: 97-102.

Montalvo, A. E. and P. L. Melendez. 1986. Histopathology of interrelations between *Fusarium oxysporum* f. sp. *dioscoreae* and two nematode species on yam. *J. Agric. Univ. Puerto Rico.* **70**: 245-254.

Mukherjee, B. and M. K. Dasgupta. 1979. Plant parasitic nematodes under different crop conditions at Sriniketan, West Bengal. *Indian J. Nematol.* **9**: 74-75.

Mukherjee, B. and M. K. Dasgupta. 1981. Prevalence and intensity of nematode infestation in tea plantations of West Bengal. *Indian J. Nematol.* **11**: 115.

Mukherji, S. K. and B. D. Sharma. 1973. Root-knot disease of *Trichosanthes dioica. Indian Phytopath.* **26**: 348-349.

Mukhopadhyay, M. C. and M. D. S. Haque. 1974. Nematodes associated with field crops, fruits and fodder crops in West Bengal. *Indian J. Nematol.* **4**: 104-107.

Mumford, B. C. 1963. *List of intercepted plant pests*, 1962. USDA, ARS, Pl. Quarant. Div. p 88.

Muthukrishnan, T. S. 1987. Notes on additional hosts of *Criconemella basili* (Jairajpuri, 1964), Luk and Ruski, 1981. *Indian J. Nematol.* **17**: 144-145.

Nadakal, A. M. 1963. Studies on the plant parasitic nematodes of Kerala. Occurrence of root-knot nematodes, *Meloidogyne* spp. (*Tylenchoidea-Heteroderidae*) on certain plants of economic importance. *J. Zool. Soc. India.* **15**: 129-133.

Nadakal, A. M. 1964b. Studies on plant parasitic nematodes of Kerala. III. An additional list of plants attacked by *Meloidogyne* spp. (*Tylenchoidea:Heteroderidae*). *J. Bombay Natur. Hist. Soc.* **61**: 467-469.

Nadakal, A. M. and N. Thomas. 1964. Studies on the plant parasitic nematodes in Kerala. *Curr. Sci.* **33**: 247-248.

Nadakal, A. M. and N. Thomas. 1967. Observations on nematodes associated with dry rot of *Dioscorea alata* L. *Sci. and Cul.* **33**: 142-143.

Nagakura, K. 1930. Uber den bau und die Lebensgeschichte der *Heterodera radicicola* (Greeff) Muller. *Jap. J. Zool.* **3**: 95-160.

Nance, N. W. 1941. Root-knot on *Humulus lupulus* and *Euonymous* spp. and *P. pratensis* on *Gilia rubra*. In: *Disease of Plants in United States in 1939. Pl. Dis. Reptr. Suppl.* **128**: 329, 360, 362.

Naqvi, S. Q. A. and M. M. Alam. 1974. Addition to the host records of the root-knot nematode, *Meloidogyne incognita* (Kofoid and White) Chitwood. *Curr. Sci.* **43**: 564.

Nath, R. P.; Swarup, G. and G. S. V. Rama Rao. 1969. Studies on the reniform nematode, *Rotylenchulus reniformis* Linford and Oliviera, 1940. *Indian Phytopath.* **22**: 99-104.

Netscher, C. and D. P. Taylor. 1979. "Physiologic variation with the genus *Meloidogyne* and its implications on integrated control." In: *Root-knot nematodes (Meloidogyne species) systematics, biology and control* (eds. Lamberti, F. and C. E. Taylor) Academic Press, London, pp. 269-304.

Newton, H. C. F. and C. Duthoit. 1954. Stem and bulb eelworm of potato. In: *New and uncommon plant diseases and pests in England and Wales. Plant Pathol.* **3**: 139-140.

Nirula, K. K. and R. Kumar. 1963. Collateral host plants of root-knot nematodes. *Curr Sci.* **32**: 221-222.

Nirula, K. K. and R. Kumar. 1964. New host records of root-knot nematodes. *Nematologica.* **10**: 184.

Nirula, K. K. and R. Kumar. 1966. Addition to host record of root-knot nematodes. *Nematologica.* **12**: 180.

Nolte, H. W. 1957. *Ditylenchus dipsaci* an Zwiebeln in Mittel Deutschland. *Nematologica.* **2** (Suppl.): 376-381.

O'Bannon, J. H.; Santo, G. S. and A. P. Nyczepir. 1982. Host range of the Columbia root-knot nematode. *Plant Dis.* **66**: 1045-1048.

Oostenbrink, M. 1950. Het. Ardappelaaltje (Heterodera rostochiensis Wollenweber), een gevaarlijke parasite voor de eenzijdige aardappel cultuur. *Versl. Meded. Plziektenk. Dienst Wageningen* **115**: 230.

Oostenbrink, M. 1954. Over den Betekenis van vrijlevende wortelaaltjes in land en tuinbouw. Versl. Mede. Plzeiktenk. *Dienst Wageningen.* **124**: 196-233.

Oostenbrink, M.; Jacob, S. and K. Kuiper. 1957. Over der waardplanten van *Pratylenchus penetrans. Tijidscher Plziek* **63**: 345-360.

Oteifa, B. A. and Elgindi, D. M. 1983. "Relative susceptibility of certain commercially important cultivars to existing biotypes of *Meloidogyne incognita* and *M. javanica* in Nile-delta, Egypt." In: *Proc. III Res. Plann. Conf. Root-knot Nematodes, Meloidogyne spp., Region VII*, Sept 13-17, 1982, Coimbra, Portugal, pp. 157-169.

Pandey, R. 1992. Effect of nematode (*Meloidogyne incognita*) on *Ammi majus* L. *Int J. Pharmacognosy.* **30**: 191-196.

Pandey, R. 1994. Comparative performace of oil seed cakes and pesticides in the management of root-knot disease of Davana. *Nematol. Medit.* **22**: 17-19.

Pandey, R.; Haseeb, A. and A. Husain. 1992. Distribution, pathogenicity and management of *Meloidogyne incognita* on *Mentha arvensis* cv. MAS-1. *Afro-Asian J. Nematol.* **2**: 27-34.

Patel, D. J.; Makadia, B. M. and H. M. Shah. 1981. Occurrence of root-knot on turmeric (*Curcuma longa* L.) and its chemical control. *Indian J. Nematol.* **11**: 125-126.

Patel, C. C.; Patel, H. R.; Patel, D. J. and N. A. Thakur. 1989. Relative susceptibility of certain medicinal and aromatic plants to root-knot nematodes. *Pak. J. Nematol.* 7: 81-82.

Pericival, J. 1895. The eelworm disease of hops. Nethlheaded or skinly plants. *Jis. East Agric. Coll. Wyel.* 5-8.

Phukan, P. N. and K. C. Sanwal. 1979. *Caloosia parapaxi* sp. n. (*Hemicycliophorinae : Tylenchidae*) from the rhizosphere of mango from Assam, India. *Indian J. Nematol.* **9**: 174-176.

Pinkerton, J. N. 1984. Relationship of *Pratylenchus penetrans* (Cobb, 1917) population density and yield of peppermint, *Mentha piperita* L. Dissertation Abstracts International, B. (Science and Engineering). **44** (12-1): 3593B.

Pinkerton, J. N. and H. J. Jensen. 1983. Chemical control of *Longidorus elongatus* on peppermint with non-volatile nematicides. *Plant Dis.* **67**: 201-203.

Pinkerton, J. N.; Jensen, H. J.; Newcomb, G. B. and R. E. Ingham. 1988. Management of *Pratylenchus penetrans* damage to peppermint with selected nematicides. *Pl. Dis.* **72**: 167-170.

Prasad, S. K. 1960a. Plant parasitic nematodes observed at the Indian Agricultural Research Institute Farm. *Indian J. Ent.* **22**: 127-128.

Prasad, S. K. 1960b. The problem of plant parasitic nematodes in India. *Indian J. Ent.* **22**: 301-304.

Prasad, S. K.; Dasgupta, D. R. and M. C. Mukhopadhyay. 1964. Nematodes associated with commercial crops in North India and host range of *Meloidogyne javanica*. *Indian J. Ent.* **26**: 438-446.

Quanjer, H. M. 1927. Een aaltjesziekte van de eardapel plant de aantastingswijze en de herkomst van haar oorzaak, *Tylenchus dipsaci* Kuhn. Tijdschr. Plziekt. **32**: 137-172.

Rajgopalan, P. and A. R. Seshadri. 1969. Pathogenicity of the root-knot nematode, *Meloidogyne arenaria* (Neal, 1889) Chitwood, 1949 to chillies *Capsicum annum* L. *All India Nematology Symp.*, New Delhi, pp. 21-22.

Rangaswami, G.; Balasubramanian, M. and V. N. Vasantarajan. 1961. The host range of sugarcane root-knot nematode, *Meloidogyne incognita* (Treub) Chitwood. *Curr. Sci.* **30**: 149-150.

Rao, Y. S. and A. Jaiprakash. 1978. *Heterodera oryzicola* n. sp. (*Nematoda – Heteroderoderidae*) a cyst nematode on rice (*Oryza sativa* L.) from Kerala State, India. *Nematologica.* **24**: 341-346.

Rashid, A.; Khan, F. A. and A. M. Khan. 1973. Plant parasitic nematodes associated with vegetables, fruits, cereals and other crops in North India 1. Uttar Pradesh. *Indian J. Nematol.* **3**: 8-23.

Rau, G. J. 1963. Three new species of *Belonolaimus* (*Nematoda – Tylenchida*) with additional data on *B. longicaudatus* and *B. gracilis. Proc. Helminth. Soc. Wash.* **30**: 119-128.

Raveendran, V. and A. M. Nadakal. 1975. An additional list of plants infected by the root-knot nematode, *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949 in Kerala. *Indian J. Nematol.* **5**: 126-127.

Ray, S. and S. N. Das. 1980. Nematodes of saline soils of Orissa, India. *Indian J. Nematol.* **10**: 231-235.

Rhoades, H. L. 1983. Effect of *Belonolaimus longicaudatus*, *Dolichodorus heterocephalus* and *Pratylenchus scribneri* on growth of peppermint. *Phytopathology.* **53**: 1164-1166.

Rhoades, H. L. 1984. Control of *Pratylenchus scribneri* on spearmint, *Mentha spicata*, with nonfumigant nematicides. *Nematropica.* **14**: 85-89.

Rhoades, H. L. 1988. Effects of several phytoparasitic nematodes on the growth of basil, *Ocimum basilicum*. *Ann. Appl. Nematol.* **2**: 22-24.

Riggs, R. D. and M. L. Hamblen. 1962. Soybean cyst nematode host studies in the family *Leguminosae. Rep. Ark. Agric. Exp. Stn. Univ. Arkansas, Ser.* **110**: 1-18.

Roy, A. K. 1972. Reaction of some plants to the attack of *Meloidogyne incognita* in Assam. *Indian J. Nematol.* **2**: 86-89.

Roy, A. K. 1973. Notes on the pathogenicity of *Xiphinema basiri* Siddiqi and its host records. *Indian J. Nematol.* **3**: 161-163.

Sasser, J. N. 1954. Identification and host-parasite relationships of certain root-knot nematodes (*Meloidogyne* sp.). *Univ. Maryland Agric. Exp. Sta. Bull. A-77*, pp 33.

Schieber, E. 1961. Parasitic nematodes on Dioscorea in Guatemala. *Pl. Dis. Reptr.* **45**: 425.

Schieber, R. and D. K. Lassmann. 1961. Root-knot nematode on *Dioscorea* in Guatemala. *Pl. Dis. Reptr.* **45**: 981.

Sen, K. and M. K. Dasgupta. 1977. Additional host of root-knot nematode, *Meloidogyne* sp. from India. *Indian J. Nematol.* **7**: 74.

Seshadri, A. R. and C. v. Sivakumar. 1963. A preliminary note on the occurrence of the reniform nematode (*Rotylenchulus reniformis*, Linford and Oliviera, 1940) on a number of cultivated crops in South India. *Madras Agric. J.* **50**: 134-137.

Sethi, C. L.; Gill, H. S. and G. Swarup. 1964. A note of the prevalence of *Meloidogyne* spp. in vegetable crops. *Indian Phytopath.* **27**: 69-70.

Sethi, C. L. and G. Swarup. 1968. Plant parasitic nematodes of North Western India. 1. The genus *Tylenchorhynchus. Nematologica.* **14**: 77-88.

Shah, H. M. and D. J. Patel. 1979. Occurrence of root-knot disease in cumin. *Indian J. Nematol.* **9**: 179-180.

Shukla, P. K. and A. Haseeb. 1996. Effectiveness of some nematicides and oil cakes in the management of *Pratylenchus thornei* on *Mentha citrata*, *M. piperita* and *M. spicata. BITE.* **51**: 307-309.

Shukla, P. K.; Haseeb, A. and S. Sharma. 1998a. Soil texture, root lesion nematode and yield of peppermint, *Mentha piperita. J. Herbs, Spices, Med. Plants.* **6**: 1-8.

Shukla, P. K.; Haseeb, A. and N. K. Srivastava. 1998b. Influence of pH on reproduction and damage potential of *Pratylenchus thornei* on *Mentha piperita. Funda. Appl. Nematol.* **21**: 103-105.

Siddiqui, M. R. 1961. Studies on *Tylenchorhynchus* species (*Nematoda – Tylenchida*) from India. *Z. Parasitenk.* **21**: 46-64.

Siddiqui, M. R. 1963. On the identity of *Belonolaimus hastulatus* Colbran, 1960 and *Tylenchorhynchus indicus* Siddiqi, 1961 (*Nematoda: Tylenchida*). *Curr. Sci.* **32**: 550-551.

Siddiqui, M. A. and M. M. Alam. 1988. Seasonal fluctuation of plant parasitic nematodes associated with two medicinal plants. *J. Indian Bot. Soc.* **67**: 231-232.

Siddiqui, Z. A.; Khan, A. M. and S. K. Saxena. 1972. Host range and varietal resistance of certain crucifers against *Tylenchorhynchus brassicae. Indian Phytopath.* **25**: 275-281.

Siddiqui, I. A., Sher, S. A. and A. M. French. 1973. *Distribution of plant- parasitic nematodes in California.* California Dept. Food Agric. Div. Plant and Sacramento, alifornia, pp 324.

Sivakumar, M. and T. Marimuthu. 1986. Efficacy of different organic amendments against phytonematodes associated with betelvine (*Piper betle* L.). *Indian J. Nematol.* **16**: 278.

Skotland, C. B. and J. D. Menzies. 1957. Two peppermint diseases found in Yakima valley of Washington. *Pl. Dis. Reptr.* **41**: 493.

Sobti, S. N.; Verma, V. and B. L. Rao. 1982. "Scope for development of new cultivars of Cymbopogons as a source of terpene chemicals." In: *Cultivation and Utilisation of Aromatic Plants* (eds. Atal, C. K. and B. M. Kapoor), Reg. Res. Lab Jammu, pp. 302-307.

Sorauer, P. 1906. *Handbuch der Pflanzenkrankheiten.* Berlin, 3 Aufl.

Sosamma, V. K. and P. K. Koshy. 1981. On the host records of *Radopholus similis. Indian J. Nematol.* **11**: 73-74.

Sosamma, V. K.; Sunderaju, P. and P. K. Koshy. 1979. Effect of *Radopholus similis* on turmeric. *Indian J. Nematol.* **9**: 27-31.

Sosa-Moss, C. 1985. "Report on the status of *Meloidogyne* research in Mexico, Central America and the Caribbean countries, pp." In: *An Advanced Treatise on Meloidogyne.* Vol.I. Biology and Control (eds. Sasser, J. N. andC. C. Carter) Coop. Publ. Dep. Plant Pathol. And U.S. Agency Int. Dev. Raleigh, N C. pp. 327-346.

Steiner, G. 1931. A nematode of yam caused by a new species of *Hoplolaimus. Pl. Dis. Reptr.* **15**: 121.

Steiner, G. 1949. Plant nematodes the grower should know. *Proc. Soil Sci. Soc. Fla.* (1942), **4B**: 72-117.

Steiner, G. and E. M. Buhrer. 1932. A list of plants attacked by *Tylenchus dipsaci*, the bulb or stem nemas. *Pl. Dis. Reptr.* **16**: 76-85.

Steiner, G. and E. M. Buhrer. 1934. Observations of interest on nematode diseases of plants. *Pl. Dis. Reptr.* **18**: 100.

Sturhan, D. 1963. Der pflanzenparasitische nematode *Longidorus maximus* seine Biologie und Okologie mit untersuchungen an *L. elongatus* and *Xiphinema diversicaudatum. Z. Angew. Zool.* **50**: 129-193.

Sultana, S. 1978. *Hirschmanniella orycrena* n. sp. and *H. oryzae* (*Nematoda-Tylenchida*) from Hyderabad, India. *Indian J. Nematol.* **8**: 174-176.

Sundaraju, P.; Koshy, P. K. and V. K. Sosamma. 1979. Plant parasitic nematodes associated with spices. *J. Plant. Crops.* **7**: 15-26.

Sundaraju, P. and C. P. Suja. 1986. Occurrence of *Radopholus similis* on betelvine (*Piper betle* L.) in Karnataka. *Indian J. Nematol.* **16**: 279.

Swarup, G.; Nath, R. P. and C. L. Sethi. 1967. The plant parasitic nematode genus *Rotylenchulus* in India. *Indian Phytopath.* **20**: 118-123.

Tarjan, A. C. 1953. Geographical distribution of some *Meloidogyne* spp. in Israel. *Pl. Dis. Reptr.* **37**: 315-316.

Tedford, E. C. 1986. Development of Meloidogyne incognita and *M. arenaria* on flue cured tobacco (*Nicotiana tabacum* L.) and selcected weed species. M. Sc. Thesis, Clemson University, Clemson SC. pp. 82.

Thirughanam, M. and G. Rangaswami. 1976. A report on the natural occurrence of root-knot nematode (*Meloidogyne* spp.) on some plants in Madras State. *Madras Agric. J.* 54: 278-282.

Thorne, G. 1936. The teasel nematode (*Nematode-Tylenchidae*). *Proc. Helminth. Soc. Wash.* **12**: 27-34.

Thorne, G. and M. L. Schuster. 1956. *Nacobbus batatiformis* n. sp. (*Nematoda-Tylenchidae*), producing galls on the roots of sugar beets and other plants. *Proc. Helminth. Soc. Wash.* **23**: 128-134.

Townshend, J. L. and T. R. Davidson. 1960. Some weed hosts of *Pratylenchus penetrans* in Premier strawberry plantations. *Can. J. Bot.* **38**: 267-273.

Upadhyay, K. D. and G. Swarup. 1972. Culturing host range and factor affecting multiplication of *Tylenchorhynchus vulgaris* on maize. *Indian J. Nematol.* **2**: 139-145.

Ustinov, A. A. 1939. "The root-knot nematode, *Heterodera marioni* (Cornu) in the USSR." In: *Collected works on nematodes of Agricultural Crops* (ed. Kirjanova, E. S.). Teningrad. Acad. Sci. Moscow and Leningrad. p 247.

Valdez, R. B. 1968. Survey identification and host parasite relationships of root-knot nematodes occurring in some parts of the Philippines. *Philipp. Agric.* **51**: 802-824.

Vanha, J. J. and J. Stocklasa. 1986. *die Rubennematoden* (*Heterodera, Dorylaimus, Tylenchus*), *mit anhang uber die Enchytraeiden.* Berlin, p 96.

Varaprasad, K. S.; Mathur, V. K. and B. R. R. Rao. 1987. On the association of some plant parasitic nematodes with corkwood tree, *Duboisia mycoporoides* and remark on abnormalities in males of *Meloidogyne incognita. Indian J. Nematol.* **17**: 281-284.

Verma, S. K. and S. K. Prasad. 1969. The reniform nematode, *Rotylenchulus reniformis* Linford and Oliviera, 1940 1. Bio-Ecological Studies. *Indian J. Entomol.* **31**: 36-47.

Voigt, W. 1890. Uber *Heterodera radicicola* Greef und *H. Shachtii* Schmid 1. Infectionsversuche zur unterscheidung von *Heterodera radicicola* und *H. schachtii.* Sber. Niederrhein. *Ges. Nat. u. Heilk.* **47**: 66-74.

Wang, K. 1978. Research on root-knot nematodes at the National Taiwan University. *Kasetsart J.* **12**: 36-42.

West, J. 1934. Dry rot of yams. *Bull. Imp. Inst.* London. **32**: 448-450.

Winslow, R. D. 1954. Provisional lists of host plants of some root eelworm (*Heterodera* spp.). *Ann. Appl. Biol.* **41**: 591-605.

Yadav, B. S. and M. K. Verma. 1967. New host plants of *Xiphinema basiri* and *Xiphinema indicum. Nematologica.* **13**: 469.

Zimmermann, A. 1899. Het. Voorkomen van nematoden in de wortels van sirih en thee. I. de aaltjesziekte der sirih (*Piper betle* L.) II. *Tylenchus acutocaudatus* Zn. In Department of thee. Taysmannia. **10**: 523-531.

❑❑❑

9

Eco-friendly Management of Cotton Nematodes

R.V. Vyas, A.D. Patel, and D.J. Patel

Introduction

Cotton (*Gossypium* spp.) is an important cash fiber crop belonging to the family malvaceae. Cotton is called as **White Gold** and occupies a predominant position as an ancient crop due to the fact that clothing is the prime need of human beings next to the food requirement. Not only it is a major commercial crop because of its fiber value but also every part of the plant is of immense use to the farmers in particular and mankind in general in one way or the other. It is divided into four main products *viz.* cottonseed oil (24-25%), cake and meal (protein supplement 37%), crude protein 43 per cent (unshelled seeds) and 24 per cent (shelled seeds), cotton seed hull (percentage least valuable) and linters (2-3%) (Josef, 1969). Cotton stalk is also enormously used as fuel and the shedding leaves on soil enrich the soil fertility by way of increasing organic content.

Cotton is cultivated almost throughout the world and grown in about 36 M ha with production of 25.9 M tons in 2004-05. Presently per capita annual consumption of fibers in the world is about 8 kg of which 3 kg is cotton. China, USA and India are the major producers of cotton. In India, it occupies about 8.96 M ha area producing about 232 lakhs bales annually (Singh *et al.*, 2005). Maharashtra, Punjab, Gujarat, Haryana, Tamil Nadu, Andhra Pradesh, Karnataka, Rajasthan, Madhya Pradesh and Chhattisgadh are the principal cotton growing states occupying about 90 per cent area under cotton in the country (Singh *et al.*, 2005). Of these, Gujarat has almost 21 lakhs ha under cotton with 75 lakhs bales production (Pers. Comm. with Ahmedabad Textile Mills Association, Ahmedabad). In India, four species of cotton *viz. Gossypium hirsutam* L., *G. barbadense* L., *G. arboreum* L. and *G. herbaceum* L. are under cultivation. Presently Bt cotton, having resistant to American bollworm is covering more than 60 per cent of the cotton cultivation in India.

Cotton is attacked by several biotic and abiotic stresses including insect-pests and diseases. Among these, fungal, bacterial and nemic diseases are important. Seedling root-

rot incited by *Rhizoctonia solani* kuhn and *R. bataticola* (Taub.) Bulter, root-knot disease caused by *Meloidogyne* spp., angular leaf spot incited by *Xanthomonas axonopodis* f.sp. *malvacearum* (E.F. Sm) Dows, anthracnose incited by *Colletotricum gossypii* south, wilt incited by *Fusarium oxysporum* f.sp. *vasinfectum* (Atk). Synder and Hansen and Verticillium wilt caused by *Verticillium albo-atrum* Reinke and Breth of which diseases induced by phytonematodes are of economic importance and increasing day by day since last few decades. Over 22 species of different plant parasitic nematodes are reported to be associated and cause eye-catching damage to cotton crop in India (Reddy, 1983). Bajaj and Bhatti (1982) reported reniform nematode (*Rotylenchulus reniformis* Linford and Oliveira, 1940); root-knot nematodes (*Meloidogyne incognita* Kofoid and White, 1919) Chitwod, 1949 and *M. javanica* (Treub,1855) Chitwood,1949; cyst nematodes (*Heterodera* spp.); stunt nematode (*Tylenchorhynchus gofarti* Sturhan, 1966); lesion nematode (*Pratylenchus thornei* Sher and Allen, 1953); lance nematode (*Hoplolaimus indicus* Sher, 1963 and *H. columbus* Sher, 1963), spiral nematode (*Helicotylenchus indicus* Siddiqi, 1963 and *H. dihystera* Cobb, 1893; Sher, 1961) and needle nematode (*Longidorus* siddiqi Aboul-Eid, 1970) as key nematodes attacking cotton in the country. Of these, root-knot (*M. incognita* and *M. javanica*), reniform (*R. reniformis*) and lance (*H. indicus*) nematodes are commonly affecting cotton production and quality in different cotton growing states in India. Nematode induces about 10.7 per cent loss in cotton yield incurring monetary loss of about US $ 4.11 billion annually (Sasser and Freckman, 1987). In Gujarat, mix population of root-knot nematodes (RKN) is observed to cause yield losses of 4.08 per cent in hybrid cotton varieties Hy 8 and 6 (Anon., 1999-2000). *R. reniformis* induces 20.8 per cent yield loss in cotton cv. Hy Cot. 8 (Anon., 2001-05). In USA, yield loss due to *M. incognita* is estimated to be 10.19 per cent (Orr and Robinson, 1984). Losses due to reniform nematode are reported to be 14.80 per cent from Tamil Nadu (Sivakumar, 1992), while *Hoplolaimus* spp. are reported to reduce cotton yield by 19.00 per cent in USA (Noe and Imbriani, 1986).

Symptoms

Root-knot Nematodes (*Meloidogyne* spp.):

Root-knot nematodes attacked cotton plants exhibit stunting, yellowing and temporary wilting symptoms in patches (Plate 1). This ultimately results in delayed crop maturity and reduction in boll size leading to reduce crop yield. Moreover, nematodes in addition to their own pathogenic effects make the entry easy for other pathogenic micro-organisms such as fungi, bacteria, viruses, etc. leading to aggravation of disease severity. On uprooting such infected plants, severe root galling is noticed (Plate 1). Their role in

breaking disease resistance is also well known. Root-knot nematode infection aggravated the intensity and severity of root-rot disease caused by *Macrophomina phaseolina* adversely affecting the crop growth and finally cotton yield.

Plate 1: Cotton field infected by root-knot nematodes (stunting effect in patches), Inset: close up view of root galling on cotton plant

Reniform Nematode (*Rotylenchulus reniformis*):

Reniform nematodes produce non-distinctive symptoms on cotton foliage often resembling to a potassium deficiency in late crop season. Symptoms on host plants include dwarfing, yellowing, leaves shedding, formation of malformed bolls and seeds (Plate 2). Damaged plants usually mature one or two weeks later than healthy plants, causing a delay in boll formation by 15 to 20 days. Stunted cotton plants usually occur in localised areas in the field where the nematodes are just getting feeding on roots. Below ground symptoms are not obvious but they include a reduced root system and necrotic lesions on the roots exhibiting ashy colour roots. Plant mortality is possible in heavy infestation. Small clumps of dirt that cling to egg masses on the roots may be visible with magnification. These clumps are smaller and less obvious than the galls formed by root-knot nematodes on roots. It has been observed that severe infection of reniform nematode produces wilt symptoms in cotton in Tamil Nadu.

Lance Nematodes (*Hoplolaimus indicus*):

Damage may show up as patches of yellowing and stunting of plants. These symptoms can also be confused with drought or nutrient deficiency. Examination of roots

of a lance nematode infected plants reveals thorough damage leading to reduction in root system. Small feeder roots are gone and root tips appear dead. If new roots have begun to grow, they usually are injured as well. It is this damage to the root system that is responsible for the foliage yellowing in patches.

Plate 2: Reniform nematode infested farmers field.

Other phytonematodes like *Heterodera, Pratylenchus, Tylenchorhynchus, Helicotylenchus* and *Longidorus* are also reported to attacks and produce symptoms on cotton as exhibited by secondary fungal infection always shows wilting and quick drying.

Interaction with Other Pathogenic Organisms

Root-knot nematodes (*M. incognita* and *M. javanica*) increased severity of root-rot incited by *M. phaseolina* and drastically hampered cotton growth and development by way of depleting the uptake of N, P, K, Ca, Mg and S (Patel, 1989; Patel *et al.*, 1994). Studies on interaction between *R. reniformis* and *R. bataticola* [= *M. phaseolina*] (virulent and avirulent strains) revealed that both *R. bataticola* strains were equally effective in causing seedling root rot in cotton cv. Hy 6 in the presence of *R. reniformis*. In the virulent strain of *R. bataticola*, the disease occurred one week earlier in different combinations of nematode and fungus (*i.e.* simultaneous fungal and nematode inoculation, fungal inoculation 15 days before nematode inoculation and nematode inoculation 15 days before fungal inoculation) than fungal inoculation alone. Among different combinations, nematode inoculation 15 days before fungal inoculation was

highly detrimental, causing 100 per cent root rot with both fungal strains (Patel *et al.*, 2004). Presence of root-knot nematode (*M. incognita*) enhanced the development and severity of cotton wilt caused by *F. oxysporium* f. sp. *vasinfectum*. The level of wilt incidence and plant growth reduction was almost more than two fold when two pathogens were present to gather (Ibrahim *et al.*, 1982).

Management

Physical Methods:

Since time immemorial agronomical practice like tillage is well followed having real impact in reducing soil micro flora and fauna. Exposing soil to solar radiation by deep ploughing during hot summer, with or without prior irrigation brings down about 50 per cent phytonematodes population in fields (Shivagami, 1995). Sub-soiling up to the depth of 35 cm for consecutive three crop seasons reduced *H. columbus* population and increased seed cotton in USA (Hussey, 1977). Burning of agricultural wastes and other crop residues (Rabbing) as well as hot water treatment in soil can also bring down nematode populations (Dasgupta and Gaur,1986) but due to high cost involved and laborious work, it is not much practised for main field crops. Other physical methods like turning and drying of soil, fallowing, etc. are useful for marginal reduction of phytonematodes in agricultural crops including cotton.

Cultural Methods:

Crop rotation, application of organic amendments in soil, change of sowing dates, resistance cultivars, etc. have found effective and economic for reduction of root-knot, reniform and lance nematodes in cotton. But farmers are reluctant to grow less remunerative crops than main cash crop like cotton and hence nematode pests are increasing day by day in farmer's fields.

Many crop cultivars and weeds are reported resistant to root-knot and reniform nematodes (Sivakumar,1992; Khan, 2005) which can be effectively employed in crop rotations. A rotation of groundnut for two consecutive years following cotton reduces *M. incognita* galls on cotton plants during third year. Previous crops like mustard and sesamum in crop rotation effectively reduce *R. reniformis* and *H. indicus* (Gaur and Haque, 1985). In general rotation of poor host crops of root-knot nematodes like wheat, maize, sorghum, barley etc. reduces root-knot disease in subsequent crops including cotton. Inter cropping of wheat in cotton reduces reniform attack on cotton with increased yield of cotton in Isreal (Shivagami,1995). About 48 different plants belonging to 13 families are poor to intermediate hosts of *R. reniformis* of which Poaceae, Brassicaceae and Liliaceae are chief one which reduces *R. reniformis* population in soil (Khan, 2005).

Resistant Cotton Cultivars

Rigorous screening of cotton varieties/cultivars/germplasm world over in last few decades has generated information on many *Gossypium* spp. resistant to root-knot nematodes (Table 1). In India also, several cotton varieties are identified resistant/tolerant to root-knot nematodes (Anon.1978-97[a], 1978-97[b], 1999-2000). Out of 491 *Gossypium* spp. screened against *R. reniformis,* 15 lines were resistant (Rajendran and Devarajan, 1998). Similarly *G. arboreum* varieties K 7 and 8-7R wild species are reported least susceptible to *R. reniformis* (Muralidharan and Sivakumar, 1975).

Table 1: Cotton Cultivars Resistant to Phytonematodes

Gossypium species	Nematode species	Country	Resistant line/cultivars/ strain	Reference
G. arboreum L.	*R. reniformis*	USA	CB 20, 27, 32, 41 & 20	Carter (1981)
G. barbadense L.	*M. incognita* *R. reniformis*	USA USA	Darwinii Texas 110	Sivakumar (1992)
G. herbacewn L.	*R. reniformis*	USA	P.I. 408775	Sivakumar (1992)
G. hirsutum L.	*R. reniformis*	India	TCH 1218 (M), KB 209 (F), TCB 218, 081, 1-948, DHB 105 & 115, MC 5, 53-D-7, CD 2482, TT Hairy, PK-1609, AC-123162, DHH-11, DCH 32, ACP-7-1, J.K. 119, Bar 12/13 & 12/19	Anon. (1978-97[a])
			G 27, G.Cot-13, 19 & 23 G. Srv. 13, G. Shv. 1111/90 Sanjay, Digvijay, AKA 189	Anon. (1999-2001[a])
			AK 80, Naiked Burin L., IC-1531, B-61-2039, H-285, JSC-34, Su-22, Co-Who-8-5 (1521), IC-284	Anon. (1978-97[b])

	R. reniformis	USA	LA 434-1031-4 TR 19 Converted TR19 TR 26 Converted TR 26 Converted TR 78 TR 176 Converted TR 176	Beasley (1986)
	M. incognita	India	HS-57, Anjali, H-1237, Sarvottam, H-1239, I 2/99-1	Anon. (1999-2001[b])
		USA	Auburn 56, Cleavaewilt 6, Auburn 623 RNR, Bayou, Tamcot SP 21, Tamcot SP 37, Tamcot CMAD-E, MDR SP 7, SP 46, Gacot 79, Pee Dee 4381, HYC-76-56, McNair, Auburn BR 2, Aauburn 82, RNR Ne, Auburn 244RNR, Auburn299 RNR, LA RNA 4-4, LA RN 909, LA RN 910, LA RN 1032	Sivakumar (1992)

Biological Control

Several antagonists like bacteria, fungi, protozoan, predatory nematodes and arthropods are actively suppressing root-knot and reniform nematodes in agro-ecosystem (Table 2). During recent years, considerable efforts have been made all over the country for such natural allies to combat nematode pests. Amongst various biotic factors,

epiphytic parasitic bacteria, *Pseudomonas* and endophytic parasitic, *Pastueria* are effectively used for control of *Meloidogyne* and *Rotylenchulus* species (Sterling, 1992). These bacteria when inoculated in the rhizosphere effectively suppress the nematode population. Application of *P. fluorescens* (PF 1) at 10^8 cfu /ml reduced *R. reniformis* penetration up to 60 per cent in cotton roots. *In vitro* studies, they have also noticed that *R. reniformis* nematodes when exposed to culture filtrate of *P. fluorescens* (25 to 100 %) found detrimental and induced quick mortality at higher doses (Jayakumar *et al.*, 2003).

But major emphasis is focused on fungal antagonists of root-knot and reniform nematodes for biological control in cotton crop. Seed treatment of with *Paecilomyces lilacinus* conidia effectively controls *M. incognita* (Davide and Zorilla, 1985). Similarly the fungus *P. lilacinus* application at sowing effectively controls reniform nematode in cotton under green house conditions (Jayakumar *et al.*, 2002). VAM fungi applications in cotton cv. TCB 209 colonised roots and reduced reniform nematodes with increased in cotton yield (Seerinivasan *et al.*, 2003).

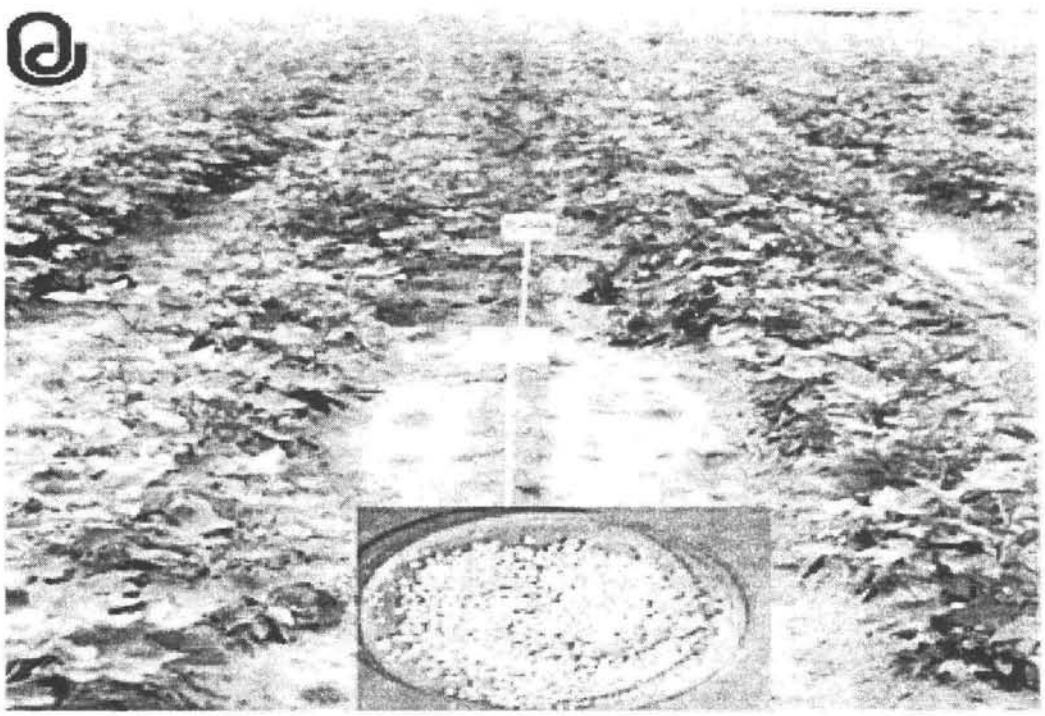


Plate 3: Biological control of root-knot nematodes in cotton PL - *P. lilacinus* treated and PL + PHEN - *P. lilacinus* and Phenamiphos treated. Inset – granular formulation of *P. lilacinus*

Biological control of root-knot disease (*Meloidogyne* spp.) by *P. lilacinus* in cotton has been successfully achieved and provided effective check under field

conditions (Plate 3). Three years pooled results indicated reduction of root-knot disease by 28.7 per cent in cotton enhancing 10.7 per cent crop yield over control when fungus was applied @ 25 kg/ha (granules/spore dust based on rice grain substrate carrier). Moreover in double whammy approach with nematicide phenamiphos fungus gave better control of root-knot nematodes (Fig 1). A simple mass production technique of the fungus based on solid substrate fermentation using broken rice grain waste and a new sodium alginate granular formulation technique have been developed for successful utilisation of this bionematicide under field conditions (Vyas and Patel, 2002).

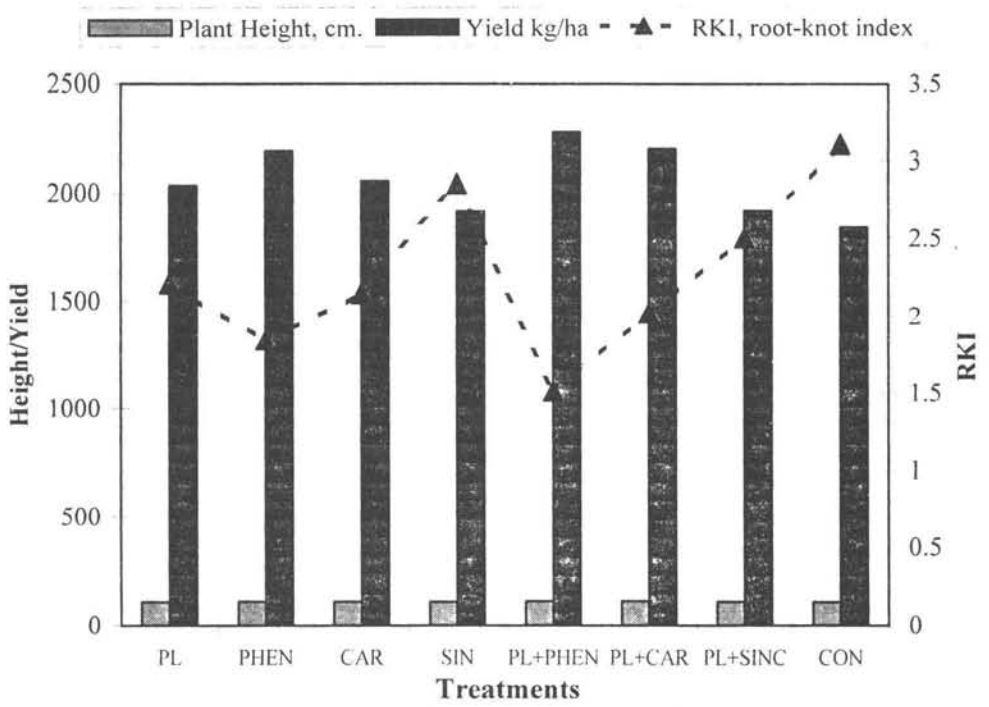


Figure 1: Efficacy of *Paecilomyces lilacinus* against root-knot nematode in cotton (3 yrs pooled)

PL- *Paecilomyces lilacinus* , PHEN - Phenamiphos, CAR - Carbofuran, SIN - Sincosin, CON - Control

Farmer's field demonstration trials on *P. lilacinus* was also carried out at village Telnar, Dist : Kheda, Central Gujarat in cotton during *kharif* 1999 followed by a farmer's meet on Sept. 9, 1999 in which more than 200 farmers participated and revealed that application of bio-nematicide, *P. lilacinus* @ 25 kg/ha (granules having spore load 5 x 10^8 conidia/g) with phenamiphos @ 1 kg/ha was found most effective for management of root-knot nematodes (*Meloidogyne* spp.) with highest yield of cotton. Phenamiphos alone and *P. lilacinus* with carbofuran @ 1 kg/ha were next effective treatments. *P. lilacinus* alone was at par with carbofuran, the popular nematicide (Anon., 1999-2000).

Table 2: Commercial Biological Control Products Based on Fungal Antagonists

Product name	Fungal Species	Type of action on nematode	Country of origin	Reference
Royal 300	*Arthrobotry superba*	Predacious	France	Cayrol (1981) Cayrol *et al.* (1978)
Royal 350	*Arthrobotrys irregular*	Predacious	France	Cayrol (1981) Cayrol *et al.* (1978)
Biocon	*Paecilomyces lilacinus*	Egg-parasitic, producing antibiotics	The Phillippines	Timm (1987)
Ditera	*Myrothecium*	Producing antibiotics	USA	Warrior *et al.* (1999)
Nemout	Fungi	--	Saudi Arab	Al-Hazmi *et al.* (1993)
Yorker	*Paecilomyces lilacinus*	Egg-parasitic, producing antibiotics	India	Vyas and Patel (2002)
Tricho X-P	*Paecilomyces lilacinus* + *Trichoderma viride*	Egg-parasitic, producing antibiotics and antagonistic	India	Vyas and Patel (2002)
Bio protect- ant	*Paecilomyces lilacinus*	Egg-parasitic, producing antibiotics	China	Liu *et al.* (1996)

Integrated Nematode Management (INM)

Integration of castor cake @ 2000 kg/ha and carbofuran @ 1.0 kg/ha significantly reduced reniform nematode by 83.15 per cent and increase cotton yield by 27.3 per cent over control (Anon., 2001-05). Application of pressmud, fresh Azolla and FYM effectively increases plant growth and reduce reniform host infestation (Patel, 1989). Bioagent, *P. lilacinus* is found more effective against root-knot nematodes in cotton when applied along with phenamiphos or carbofuran nematicides (Vyas and Patel, 2002).

References

Al-Hazmi, A. S., Ibrahim, A.A.M. and Abdul-Raziq (1993). "Paecilomyces lilacinus– A nematode biocontrol agent." In: *Nematode Bio control–Aspects and Prospects* (eds. M. S. Jayrajpuri, M.M. Alam and I. Ahmed), CBS Publishers & Distributors, New Delhi, India. pp. 139-149.

Anonymous (1978-97[a]). *Two decades of research in Nematology, AICRP on Nematodes*, Tamil Nadu Agricultural University, Coimbatore. Tamil Nadu, India. p. 15.

Anonymous (1978-97[b]). *Two decades of research in Nematology, AICRP on Nematodes*, Mahatma Phula Krishi Vishvadyala, Rahuri, Maharastra, India. p. 24.

Anonymous (1999-2000). Annual Report, Dept. of Nematology, (Recommendation No. 1 & 4), BACA, GAU, Anand, Gujarat, India. pp. 90-94.

Anonymous, (1999-2001[a]). *Biennial Report, AICRP on Nematodes*, TNAU, Coimbatore, Tamil Nadu, India.

Anonymous (1999-2001[b]). *Biennial Report of AICRP on Nematodes*, HAU, Hisar, Haryana, India. pp. 68-69.

Anonymous (2001-2005). "Consolidated report of ICAR ad hoc network project on Studies on reniform nematode," *Rotylenchulus reniformis*, Dept. of Nematology, BACA, GAU, Anand (Gujarat), India.

Bajaj, H.K. and D.S. Bhatti (1982). Nematodes associated with cotton in Haryana and Punjab with description of two new leptonchid nematodes. *Indian. J. Nematol* **12**: 6-13.

Beasley, J.P. (1986). Evaluation of cotton *Gossypium hirsutum* L., genotypes for resistance to the reniform nematode, *Rotylenchulus reniformis. Dissertation Abstr. Int. B.* (Science and Engineering) 47: 856 (Fide: *Hel. Abstr. Series B.*). **56:** 45.

Carter, W.W. (1981). Resistance and resistant reaction of *Gossypium arboreum* to the reniform nematode, *Rotylenchulus reniformis J. Nematol.* **13:** 368-374.

Cayrol, J.C. Frankowski, J.P., Lariece A., Hardemare, G.D. and Talon, J.P. (1978). Control of nematodes in mushroom cultures. Statement of a method of biological control using a predatory Hyphomycetes : *Arthrobotrys robusta* strain Antipolis (Royal 300) Pepinieristes Horticultures Maraichers, *Revue Horticole* **184**: 23-30.

Cayrol, J.C. (1981). Possibilities of biological control of *Meloidogyne* nematode crop pest with the use of the "R 350 " nematophagous fungus *Arthrobotrys irregularis* . *La Defense des Vegetaux* **35**: 279-282.

Dasgupta, D.R. and Gaur, H.S. (1986). "The root-knot nematodes *Meloidogyne* spp. in India." In : *Plant parasitic nematodes of India* (Eds. Gopal Swarup and D.R. DasGupta , IARI, New Delhi, p. 139-171.

Davide, R.G. and Zorilla, R.A. (1985). Evaluation of fungus *Paecilomyces lilacinus* for the biological control of root-knot nematodes *Meloidogyne incognita* on okra as compared with nematicide isazofos. *Philippine Agriculture* **68**: 493-500.

Gaur, H.S. and Haque, M.M. (1985). Influence of weed control practices on nematode population dynamic under different cropping sequences. *Indian J Nematol.* **15**: 263.

Hussey, R.S. (1977). Effect of sub soiling and nematicides on *Hoplolaimus columbus* populations and cotton yield. *J Nematol.* **9**: 85-96.

Ibrahim, I. K.A., M.A Rezk and H.A.A. Khalil (1982). Effect of *Meloidogyne incognita* and *Fusarium oxysporum* f. sp. *vasinfectum* on growth and mineral content of cotton, *Gossypium barbadense* L. *Nematologica* **28**: 298-302.

Jayakumar, J., Ramakrishnan, S. and Rajendran, G. (2002). Effect of culture filterate of *Pseudomonas fluorescens* strain PF 1 on cotton reniform nematode, *Rotylenculus reniformis*, *Indian J Nematol.* **32**: 228-230.

Jayakumar, J., Ramakrishan, S. and Rajendran, G. (2003). Effect of *P. fluorescens* strain on reniform nematode, *R. reniformis* penetration in cotton. *Current Nematol.* **13**: 43-45.

Josef, B. (1969). "Use of cotton plant products." In: *The Words Major Fibre Crops Their cultivation and Manuring Centre Detude De Lazote* 6 : *Zurich* pp. 13-17.

Khan, M.R. (2005). Hosts and non hosts of reniform nematode, *Rotylenchulus reniformis* Linford & Oliveira, 1940 – a critical review. *Environment and Ecology,* **23**: 124-140.

Liu, X.Y., Sun, M. H. Gao, R.J. , Zhang, X.D., Xie Y, Q and Qiu, W.F. (1996). "Biological control of soybean cyst nematode in china." pp. 11-14. In: Tang, W. Cook, R.J. and Rovira, A. eds. *Proceedings of international workshop on Biological control of plant diseases*, Beijing, May 22-27, 1996, China Agriculture University Press.

Muralidharan, R. and Sivakumar, C.V. (1975). Susceptibility of certain Indian varieties of cotton and species of *Gossypium* to the reniform nematode, *Rotylenchulus reniformis. Indian J Nematol.* **5**: 116-118.

Noe, J.P. and Imbriani, J. L. (1986). Yield loss relationships and population dynamics of *Hoplolaimus columbus* on cotton as modified by edaphic parameters. *J Nematol.* **18**: 624.

Orr. C.C. and Robinson, A.F. (1984). Assessment of cotton yield in Western Texas caused by *Meloidogyne incognita. Plant Dis.* **68**: 284-285.

Patel, R.R. (1989). Studies on the reniform nematode, *Rotylenchulus reniformis*, infecting cotton. M.Sc. (Agri.) Thesis submitted to Gujarat Agricultural University , Sardar Krushinagar-385 506, Gujarat.

Patel, N.B., D.J. Patel, D.B. Patel and P.B. Patel (1995). Interaction between root-knot nematode (*Meloidogyne incognita*) (Kofoid and White) chitwood and *Meloidogyne javanica* (Treub) Chitwood and *Macrophomina phoserbina* (Tassi) Gold on cotton. *Current Nematol* . **6**: 61-66.

Patel, R.R., B.A. Patel and N.A. Thakar (2004). Role of reniform nematode, *Rotylenchulus reniformis* in the incidence of root-rot, *Rhizoctonia bataticola* on cotton. *Indian J. Nematol.* **34**: 19-21.

Rajendran, G. and Devarajan, K. (1998). "Screening of *Gossypium* spp. against reniform nematode and fungi." In: *Proceeding on Nematology, Challenges and opportunities in 21st Century Third International Symposium Afro Asian Society of Nematologists* (Ed. U. K. Mehta), Sugarcane breeding Institute, Coimbatore, India. 119-122.

Reddy, P.P. (1983). "Diseases caused by nematodes." In: *Plant Nematology*, Agricole Publishing Academy, New Delhi. pp. 219-222.

Sasser, J.N. and D.W. Freckman. (1987). "A World perspective on Nematology The role of society." In: *Vistas on Nematology*. Ed. by J.A. Veech and D.W. Dickson. The Society of Nematologists, Inc., Maryland, USA. pp. 7-15.

Seerinivasan, N. Rajeswari Sundarababu Devrajan, K. and Rajendran, G. (2003). Influence of VAM fungi on cotton (*Gossypium barbadense* L.) infested with reniform nematodes, *Indian J Nematol.* **33**: 52-55.

Shivagami, V. (1995). "Nematode problems in cotton" (chapter 32) In: *Nematode pest management–An appraisal and ecofriendly approaches* (eds. Gopal Swarup, D.R. Dasgupta and J.S. Gill), Nematological Society of India, Division of Nematology, IARI, Pusa, New Delhi, pp. 239-243.

Singh, R., M. Gupta and N. Agrawal (2005). *Commodity scenario cotton Progressive Farming*, July 2005. p. 23.

Sterling, G.R. (1992). *Biological control of plant parasitic nematodes*, CAB International, Walling Ford, UK, p. 281.

Sivakumar, C.V. (1992). "Nematodes Pests of cotton." In: *Nematode Pests of Crops* (Eds. D.S. Bhatti and R.K. Walia), CBS Publishing and Distributors, Delhi, pp. 202-213.

Timm, M. (1987). Biocon controls nematodes biologically. *Bio Technology* **5**: 72-74.

Vyas, R.V. and Patel, D.J. (2002). Biological control of root-knot nematodes in India : *Ann. Rev. Plant Pathol.* **1**: 137-154.

Warrior, P., Rehberger L.A., Beach M., Grau, P.A. Kirfman, G.W. and Conley, J.M. (1999). Commercial development and introduction of Di Tera, a new nematicide. *Pesticide Sci.* **55**: 376-379.

❑❑❑

10

Management of Nematodes in Sugarcane

Dr. Usha K. Mehta

Introduction

Sugarcane, the sweet crop is an annual crop followed by two or three ratoons in our country but six to seven ratoons in Australia, Cuba, Hawaii and other countries, making is almost a perennial plantation crop. In fact sugarcane is now cultivated almost as a monocrop in the sugar factory regions. This long-term affect of the crop in a field is subjected to many biotic conditions, specially pests and diseases. Although sugar (crystals of sucrose) is the main product of sugarcane, it also provides commercial quantities of fiber and fuel. Byproducts of sugar industry are used in the manufacture of alcohol, paper, cattle feed, pharmaceuticals, and organic fertilizers.

Sugarcane crop as being a good host for nematodes has been recorded from very early days of plant Nematology history. Earlier Nematologist working in the tropics have recorded many important general and species of nematodes from the sugarcane rhizosphere. Treub, as early as 1885, described predominant genera of today, Meloidogyne, as *Heterodera javanica* Treub (1885) from Cheribon and Bogar in Java. Following this, another ruling genus of today, *Pratylenchus* was described by Soltwedel (1887) from the same country, as *Tylenchus sacchari* (Soltwedel, 1887). Cobb (1893) discovered a new nematode *Tylenchus similes* from Hawaii and has described in detail the losses to sugarcane by the nematode. This nematodes now renamed as *Radopholus similes*, is major pathogen of many plantation crops including sugarcane. *Tylenchus dihystera* was also recorded by Cobb (1893), as being prevalent in Hawaii. Even in those earlier days Cobb had described diseases caused by nematode alone and also complex disease in association with bacteria and fungi.

Plant-parasitic nematodes are microscopic roundworms that feed on and damage plants. In India, occurrence of root-knot nematodes in sugarcane was first reported by Barber (1919) from Coimbatore, Tamil Nadu state. *Pratylenchus* is found distributed in

the entire sugarcane tract world wide. However, the population level of the nematode and the species found, vary in its geographical distribution. The most frequently occurring species is *P.zeae* which generally occurs in a high population and is also widely distributed. Other species recorded *are P.coffeae, P.delattrei, P. goodeyi* and *P.pratensis*. Pratylenchus species are known to occur more in heavy clayey soils of southern zone of Tamil Nadu and Kerala, constituting 75 per cent of total nematode population, while it forms 40 per cent of the populations in Andhra Pradesh, Madhya Pradesh, Maharashtra and Punjab, and only 20-30 per cent in Uttar Pradesh and Gujarat, respectively.

Sugarcane roots that are damaged by ectoparasitic nematodes may appear stubby, coarse, and discolored, and lack feeder roots. The endoparasitic lesion and lance nematodes cause reddish lesions, and in severe infestations cause discoloration and rotting of the root system. Root-knot nematodes may cause swellings or galls on roots, but on sugarcane these galls are not as large as on vegetable crops. It should be noted that in the field it is common for multiple nematode genera to cause damage in the same field. Therefore, a mixture of root symptoms may occur together on the same plants.

The above ground symptoms associated with sugarcane crop affected by these nematode are almost similar to that of general symptoms of nematode attack in any other crop. Usually paling of the leaves, first in the form of streaks, later complete yellowing-chlorosis, occurring in patches spread out all over the fields can be noticed. This is more emphasised in fields which do not have proper leveling done before planting. In fields having even a slight slope there is a tendency for the crop at the lower end to be gradually more chlorotic due to accumulation of water and consequently of the transport of nematodes also to the lower level. This chlorosis in severe cases, accompanied by drying up of the margins and leaf tips is more common in young crop and in ratoons. Where there is high infestation, the chlorotic condition continues in the older crops followed by stunting of the crop and reduction in number and size of internodes. Sometimes the entire field is affected and is pale-green to whitish in look.

Crop Losses

Plant parasitic nematodes have been recognised as an important biotic constraint in sugarcane production in many sugarcane growing countries. Plant parasitic nematodes cause an average annual crop loss of 15.3 per cent globally. In India, crop loss caused by nematodes in sugarcane was estimated to be 10-40 per cent. The losses will be much higher when nematodes are associated with other soil borne pathogens forming disease complexes.

Eco-friendly Management of Phytonematodes in Field

Sugarcane ecosystem is not only rich in number of plant parasitic nematode general but also in number of species within each genus. Nematode communities play an important role in regulating sugarcane production. Emphasis should be given for developing integrated nematode management strategies that will suppress the plant parasitic nematodes but do not harm the beneficial nematode like free-living and insect parasitic nematode in the soil (Mehta and Somasekhar, 2002).

In sugarcane fields successful nematode management can be achieved by integrating the following practices together depending on the nematode population and location and other agricultural practices adopted in the locally (Mehta, 1992).

Fallowing

Keeping the field for period of time without suitable hosts for the nematodes is basically to deprive them of food and consequently prevent rapid multiplication. However, most farmer generally will not keep their fields fallow, without any income. Fallowing is a practice to be induced in the sugar factory zones where sugarcane is cultivated in continuous monocultural practices. Once the crop is harvested all the stubbles and roots should be removed and the field maintained as clean ground.

Deep Ploughing and Solarisation

The rhizosphere of this crop is frequently undisturbed for a period of two to three years. This makes the root zone a very suitable ecological niche for rapid multiplication of the favoured species. After the final harvest of the crop, deep ploughing (with disc) the field assists in complete drying of small roots, and desiccates the soil and the nematode. If this process is repeated at least two to three times before final field preparation, the nematode population in surface zone of rhizosphere gets depreciated rapidly. Furthermore, this process of deep ploughing and natural solarisation requires only a month before final field preparation and hence is beneficial to the farmer. In addition to natural solarisation, covering the field with PVC sheets increase the soil temperature. The higher temperature assists in quick reduction of population. The temperature increases to 46°C and withholding this temperature for atleast 24 hours ensures a good level of control.

Flooding

Plant-parasitic nematodes are affected by flooded conditions. In certain areas flooding may be used as a nematode management tactic for sugarcane. For best results,

the area needs to be flooded for a 4 week period, then drained and left dry for 2 weeks, and then flooded once again for 4 weeks. This flooding will sink the nematodes about 8-10 inches deep in the soil and hence will not be able to reach the root zone. This helps the crop from being affected by the nematodes.

Crop Rotation

Rotation with wetland rice can reduce populations of plant-parasitic nematodes. Many of the nematodes that feed on sugarcane are able to feed on rice under dry conditions. However, because rice is normally grown in standing water, most of the nematodes are killed by the flooded conditions.

If vegetables are to be planted following sugarcane, it is important that nematode assays be conducted before planting the vegetables. Often, root-knot, sting, or other nematodes may build up to large numbers on the sugarcane and then cause extensive damage to the vegetable crop.

Rotation of major crop with short duration trap crops and antagonistic crops help in control of nematodes. Sunnhemp (*Crotolaria juncea*) reduces the nematode population 25 per cent.

Mustard (*Brassica rapa*) can be used successfully as a rotational crop. Being antagonistic crop to many nematodes, there is overall reduction in nematode population by 27 per cent. This crop can be used as the winter crop in the sub-tropics, following which planting of sugarcane gives an increased yield.

In sub-tropics, planting of gingelly has been found to suppress the nematode population by 36 per cent. Proposed planting schedule can then be adjusted as gingelly in January to March followed by sugarcane in April.

This manipulation of the cropping sequence helps in restricting the intensity of nematode attack and also brings a better remuneration to the farmer.

Application of Organic Manure

Organic manure has consequently reduced the other soil microflora and fauna which are a good source of biocontrol agents to many other pests. Hence there is always a need to add organic manure to the fields for proper crop management.

Farm yard manure (cowdung) is the highly favoured organic manure. This manure during its stages of degradation helps in build-up of various nematode destroying micro-organisms. Besides this, farmyard manure is a good source of nutrients to the crop.

Biological Control

Biological control methods in nematodes of sugarcane is not practical as yet, However, the common nemtophaous fungi *viz.*, *Arthobotrys cladodes*, *A. conoides*, *A. oligosperma*, *Dactylella ellipsospora* and *Dactylella* sp. were isolated by Chu and Hsu (1965) from Taiwan sugarcane soils. *Caternaria vermicola* is also found in sugarcane soils of Tamil Nadu. The fungus has been isolated from sugarcane soils even today.

Several microbial pathogens are effective against nematodes. These include the bacteria *Pasteuria penetrans* (formerly known as *Bacillus penetrans*), *Bacillus thuringiensis* (available in insecticidal formulations) and *Burkholderia cepacia.* Nematicidal fungi include *Trichoderma harzianum*, *Hirsutella rhossiliensis*, *Hirsutella minnesotensis*, *Verticillium chlamydosporum*, *Arthrobotrys dactyloides* and *Paceilomyces lilacinus*. Another fungus, *Myrothecium verrucaria*, found to be highly effective in the control of nematodes, is available in a commercial formulation, DiTera™, from Abbott Laboratories. Circle One, Inc. offers a combination of several beneficial fungi in a nematode-control product called Prosper-Nema™. Market VI offers the bacterium Burkholderia cepacia in a product called Deny™. Rincon-Vitova has a product called Activate™ whose active ingredient is the bacterium Bacillus chitinosporus.

The insect-attacking nematode *Steinernema riobravis* can provide root-knot nematode control comparable to that achieved with chemical nematicides . Although the exact mechanisms of control are not known, researchers hypothesize that there is an allelochemical involved (perhaps manufactured by symbiotic bacteria that live within *S. riobravis*) that repels plant-parasitic nematodes. Those interested in using this biocontrol will need to experiment with application rates and techniques to develop methods best suited to their operations.

A soil-dwelling predatory mite, Hypoaspis miles, preys primarily on fungus-gnat larvae but will also attack spring tails, thrips, and nematodes. These mites are available commercially for the control of fungus gnats in greenhouse production of tomatoes, peppers, cucumbers, flowers, and foliage plants. The mites are applied to the planting media.

It is clear that there is a wide range of organisms that feed on, kill, or repel nematodes. These organisms are most effective, and are found most commonly, in healthy, well-managed soils.

Resistant Varieties

Sugarcane being a vegetatively propagated plant shows a slow decline in yield and quality. This has urged the breeding of better and newer varieties to replace the existing declining varieties. The complex of pest and disease adds on to the need for replacement of varieties. As the number of varieties is on increase, it is found that the host-preference level also varies in nematode pathogenicity, some varieties being more susceptible resistant to some nematodes.

The above control measures need to be selected and collaborated together for an efficient control based on the nematodes involved, populations' level, variety of cane used, selection of previous crop etc. This then involves the necessity for a thorough study of nematodes in all aspects for the crop.

References

Chu, H.T. and Hsu, S.C 1965. *Rep. Taiwan Sug. Exp. Stn.* **37**: 81-88.

Cobb, N.A. 1893 *Agr.Gazette.* N.S Wales. pp. 808-83.

Barber, C.A. 1919. *International Sugar Journal* **252** XXI: 601.

Mehta and Somasekhar, 2002. "Diversity of plant parasitic Nematodes in Sugarcane Ecosystem." In: *Nematode Diversity.* (Ed. M. Shamim Jairajpuri) Silverline Printers, Hyderabad.) pp. 475-493.

Mehta.U.K, 1992. "Nematode Pests of Sugarcane." In: *Nematode of Pest of Crops.* (Eds. D.S. Bhatti and R.K. Walia). CBS Publishers & Distributors, Delhi. pp. 159-176.

Soltwedel, P. 1887. *Bylage Archief Voor de Java Suberindustice*, pp. 7-12.

❑❑❑

11

Management of Potato Nematodes

K.S. Krishna Prasad

Introduction

The cultivated potato *(Solanum tuberosum)* is a native of Andes mountain of South America and was introduced to India in the early 17th century by European colonizers. Basically, this crop is more suited to the temperate climatic conditions. However, the flexibility of growing the crop under varying situations of sub-tropical conditions and its adaptability to warmer climatic conditions of the tropics has been well exploited to meet the increasing demand of food supply throughout the world specifically in India. It is expected that potato would serve as a major source of food in the 21st century particularly in the developing countries. Presently the crop is cultivated in about 135 countries throughout the world with an annual production of 320 million tonnes from an area of about 20 million hectares. The present area under potato in India is about 1.15 million hectares, which is about 0.4 per cent of total cropped area. The crop is cultivated throughout the country under varying ecological situations almost throughout the year. The annual production is about 25 millions (an estimated value of Rs. 100,000 million) which is about 4.5 per cent of the output value of agricultural sub-sector in the country.

The estimated annual potato production in the world is about 450 million tonnes comparable to the actual achievement of 320 million tonnes. This is due to losses through diseases (12%); pests (7%); nematodes (11%); weeds (3%) and other causes (2%). The nematode parasites have been known to affect the potato crop for the past 125 years and presently about 156 species belonging to 52 genera are reported to be associated with the crop around the world. Our country, which is placed 3rd in potato production, accounts for 93 species of nematodes belonging to about 40 genera. Among these the potato cyst nematodes (PCN) and the root knot nematodes (RKN) have been recognised as the major nematode parasites not only in our country but also in the world. The potato cyst nematodes are prevalent in the South Indian hills while the root-knot nematodes on

potato are distributed throughout the country. In addition the stunt, spiral, lesion and reniform nematodes have also been constantly encountered in the potato cultivation, which may later become key pests of the crop in the changing agricultural scenario.

Potato Cyst Nematode

The potato cyst nematode, popularly known as the **Golden nematode of potato,** has established as one of the major crop protection problems of the world. An average loss of about 9 per cent global potato is accounted to these nematodes amounting to 45 million tonnes. These nematodes are able to build up to damageable levels in a short span of 5-6 years causing substantial yield reductions in the crop. Lack of inexpensive nematicides for soil treatment capable of providing adequate level of control under field conditions, the relative ease with which the cysts are dispersed with soil adhering to the seed tubers and the long persistence of eggs within the cysts in the absence of the host makes this nematode as probably the most important pest problem of all cultivated crops.

Distribution

Andes mountain of South America has been considered to be the original home for the cyst nematode, which are thought to have originated along with their host potato. The cysts must have got introduced into Europe with the breeding material brought for late blight disease resistance in 1850s and later spread throughout the world with the improved potatoes developed in Europe at that time. So, Europe has been considered as the secondary distribution centre and at present these nematodes are prevalent in about 60 countries. The yellow cyst nematode, *Globodera rostochiensis* is more widespread being reported from 58 countries while *G. pallida* characterised by white females, is prevalent in about 27 countries. The later species is able to adopt itself under subtropical climatic conditions and shows a wide genetic variability in its original home Andes Mountains.

In India, Dr. F.G.W. Jones, who was on a personal trip to Ootacamund, detected the nematode in 1961 at Nilgiris. This detection triggered the **organised nematological research** in the country. The nematode was probably introduced from British Islands since these fields contained European weeds. Later their occurrence was noticed in Kodaikanal hills also. Detailed surveys conducted earlier in other major potato growing areas of Assam, Karnataka, Himachal Pradesh, Punjab and Uttar Pradesh had indicated that this nematode was absent in these states confirming its prevalence only in Tamil Nadu State. Realising the potential danger of this nematode to potato cultivation in the country, the Destructive Insect Pest Act 1919 was amended by the Tamil Nadu

Government in 1971 to ensure strict checking of potato for marketing from infested fields.

A massive chemical control attempt was also made under the Indo-German Nilgiris Development Project during 1971-75. The treatment was made mandatory under the Tamil Nadu Pest Act 1971 and all the infested fields at that time in the Nilgiris were treated at the rate of 30 kg a.i./ha of fensulfothion in the first year followed by 15 kg a.i./ha in the next year. In spite of 15 times more quantity of nematicide applied in comparison of present day recommendation @2 kg a.i./ha, the potato cyst nematode is still a major constraint of potato production in Nilgiri and Kodaikanal hills. Of late, this nematode has been recorded from potato fields of neighbouring states of Karnataka and Kerala. Although the cysts observed at Karnataka were non viable, these pose as a major quarantine problem which calls for strict vigilance in enforcing domestic quarantine.

Species and Pathotypes

Julius Kuhn first noticed this nematode in 1881 at Rostoch in Germany, which was thought to be a strain of sugar beet cyst nematode, *Heterodera schactii.* Wollenweber observed differences between these two nematodes in 1923 and he isolated them as *H. schactii var. rostochiensis* denoting the place where they were first noticed. Later, Franklin in 1940 recognised it as an independent species, *H. rostochiensis.* Further developments in breeding potato for resistance to these nematodes, separation of round cyst nematodes as genus *Globodera* and detailed studies on chromo genesis and morphology of potato cyst nematode variants, made it clear that they are two species. The populations with white or cream coloured females were designated as *G. pallida* while those with golden yellow coloured females being retained as *G. rostochiensis.* Although the females of these two species could be differentiated initially by their colour at developing stage, it is difficult to separate them once they become brown cysts at which stage they cannot be easily distinguished by other *Globodera* species.

The identification of prevalent cyst nematode species from different localities in Nilgiris has indicated that both *G. pallida* and *G. rostochiensis* are prevalent at most of the localities surveyed in mixed populations. At Kodaikanal hills also both the species were encountered. Although, the cysts found at Karnataka in potato soil could not be characterised, *G. pallida* was found associated with potato at Kerala. Studies on pathotypes have indicated that Ootacamund populations constituted mainly 'Ro1' of *G. rostochiensis* and 'Pa2' of *G. pallida.* The other prevalent pathotypes were Ro2 and Ro5 of the former and Pa1 and Pa3 of the later species.

Biology

The hatching of larvae from cysts is initiated by root diffuses of members of family 'Solanaceae'. The 2nd stage larvae hatched out of the cyst move actively in the soil, invade the roots and lie parallel to the vascular system. This infection results in the formation of giant cells from which the nematodes extract nourishment. The larvae undergo successive molts increasing in size each time to reach a spherical shaped female. The adult female remains attached to the roots with its neck. These females are about 0.7 mm to 0.8 mm in diameter and are yellow or white in colour, which gradually turn brown. At the time of harvest, these brown cysts containing eggs are easily dislodged into the soil. The eggs may remain viable upto 15 years in the absence of potato root diffussates. The male nematodes retain their thread like appearance and come out freely from the root system and help the female in fertilizing the eggs.

The laboratory studies have indicated that the 2nd stage larvae took 37-39 days during summer crop (April-July) and 40-42 days during autumn crop (September-December) to become cyst at Ootacamund. Generally, one generation is completed in one crop season but there are evidences of 2nd generation of *G. rostochiensis* being completed, because of its shorter dormancy of 45 to 60 days and longer duration of the crop upto 120 days. However, *G. pallida* has a dormancy period ranging from 60 to 75 days. The multiplication rate for both the species was 7 to 13 times in summer crop and 6 to 11 times in autumn crop when the temperatures normally ranged between 15° to 21°C at Ootacamund. Recent studies have shown that *G. pallida* is able to develop and reproduce in the foot hills of Nilgiris situated at 300 to 350 meters above sea level during October to February where the temperatures ranged from 14° to 19°C minimum and 22 to 30°C maximum. However, *G. rostochiensis* could develop into females only below 25°C that were prevalent in altitude of 1400 meters and above. The cysts with eggs within them usually spread along with the soil adhering to farm implements, harvested tubers, gunny bags, etc. Other major means of spread are compost, labourer's feet, and seed potatoes. The experimental evidence of cysts being carried through wind was also observed during monsoon months in Nilgiris and water running down the slopes transmitted cysts from infested fields to nematode free fields.

Management

The potato cyst nematodes are the most successful plant parasitic nematodes exhibiting a highly specialised survival mechanism. They are restricted to a limited host range in family solanaceae and have got themselves distributed along with their host

adjusting to the surrounding variations. The experience has shown that they cannot be completely eradicated once they establish in a given locality and thus they have to be managed by adopting several plant protection strategies.

Cultural practices–Growing non-host crops and following crop rotation at least for one year with any non-solanaceous vegetables such as beetroots, cabbage, carrots, cauliflower, French beans, garlic, radish, turnips, etc., during autumn season brings down the cyst populations to a great extent, and thus the management of cyst nematode becomes more feasible. The four-year rotational sequence using potato French beans-peas had decreased the cyst populations by 98 to 99 per cent and increased yields in potato. Presently the Nilgiri farmers adopt Potato-Cabbage-Carrots for the best management of potato cyst nematodes, which also helps in maximum utilisation of nutrients applied to the soil.

Breeding for resistance–Research work on breeding for cyst nematode resistance began at CPRS, Ootacamund in 1968 and the initial studies indicated high degree of resistance in *S. ajanhurri, S. bulbocastanum, S. gandarlassi* and *S. tuberosum* sub-species *andigena, S. vernei* and *S. spegazzinii.* A large hybrid seedling population was produced using resistant *S. tuberosum* sub-species andigena clones, *S. multidissectum* (selection No. 3246) obtained from Scottish Plant Breeding Station, Edinburgh, UK and some commercial varieties as parental material. Testing of these hybrids had indicated 3 hybrids possessing high degree of resistance to cyst nematodes. However, further studies and screening showed that genotypes reported resistant earlier proved to be susceptible since there existed two nematode species and several pathotypes occurred within them. Subsequent screening of germplasm in later years showed that resistance was available in several clones of tuber bearing *Solanum* species.

High degree of resistance to several populations of cyst nematode was exhibited in *S. vernei* clone Vin2 62-33-3 obtained from the Netherlands. This hybrid was highly susceptible to late blight disease. Hence, 'Kufri Jyothi' a late blight resistant commercial variety was used as female parent with this clone to obtain several genotypes. One selecting bearing no. 110 possessed desirable yield characters in addition to reducing the cyst populations below the initial inoculum's level. This selection has been released as 'Kufri Swarna' in 1985 that presently occupies about 40 per cent of potato area in Nilgiris. Observations recorded in our farms as well as in the farmer's field has shown that this variety perform well even under drought conditions that is seen specifically under Nilgiri conditions.

Although there is no much difference in larval penetration, the nematode development in K. Swarna was only 1.07 per cent compared to 36.07 per cent in Kufri Jyothi, standard susceptible potato. Another advanced hybrid D-79-56 that was consistently performing better, is tolerant to cyst nematodes and highly resistant to late blight disease is available to farmers as 'Kufri Thenmalai'. At present there are 23 advance hybrids possessing combined resistance to both species of PCN and the late blight disease with very good agronomic characters are available, of which two hybrids are under adaptability evaluation in farmer's fields.

The availability of combined resistance in several advance hybrids to both the major plant protection problems indicates that there is an excellent opportunity to manage these problems in Nilgiris. However, since major genes occurring in wild species are used for resistance to both the diseases the protective effect could be nullified since both the parasite and pathogen is able to adopt itself to the new environment as has happened in several cases. It is suggested that for country like ours where legal restrictions cannot be forced to check cyst nematodes by resistant varieties, breeding tolerant varieties seems to offer better prospects than using major genes for resistance.

Biological Management

The use of nematode antagonistic microorganism for control of potato cyst nematodes has been attempted throughout the world with less success. This has been mainly due to the non-mobility of these organisms in search of target nematodes and their non-adaptability to the existing environment. Further lack of basic information on these organisms and inadequate studies for field implementation on large scale have made this most prospective and promising management practice as the least effective one. Very limited work done at CPRS, Ootacamund has shown that 13 fungi were able to infect the cysts and cyst contents from nearly 60 fungal colonies isolated from soils of Nilgiris. Two bioagents obtained from Project Directorate of Biological Control, Bangalore, *Paecilomyces lilacinus* and *Pochonia chlamydosporia* have shown promise under Nilgiris conditions and are being tested for PCN management.

Chemical Management

Initially halogenated hydrocarbons such as DD (1-3 Dichloropropane 1-2 Dichloropropene), EDB (Ethylene dibromide), MBr (Methyl bromide), DBCP (Dibromochloropropene), Dorlone (mixture of DD and EDB) were used for controlling potato cyst nematodes. Later, after standardisation of use of systemic pesticides,

carbofuran or phorate at 2 kg a.i/ha is effectively used for economical management of potato cyst nematodes under Nilgiri conditions.

Integrated Management

The experience has shown that potato cyst nematodes cannot be completely eradicated once they establish in a locality. They have to be managed by adopting several plant protection strategies. The restriction of the parasite only to a selected host range has helped in the management of the problem to a great extent. The Indian populations containing pathotypes Ro1, Ro2 and Ro5 of *G. rostochiensis* and Pa1 and Pa2 of *G. pallida* can be managed by *S. vernei* source as it combines resistance to these populations. Now the problem is being managed in Nilgiris by chemical treatments, crop rotations and utilising the available sources of resistance in tuber bearing *Solanum* species. Initially, several halogenated hydrocarbons were used as fumigants. Due to the hazardous nature and difficulties in application of these pesticides systemic granular pesticides slowly replaced them. The escalating costs of these pesticides, associated residual problems and slow build up of nematode populations to unmanageable levels have made chemical treatments as uneconomical at several places. Crop rotations with cabbage or carrot, intercropping beans and wheat followed by fodder oats or short duration crops like radish or French beans are economically used along with resistant potatoes. However, there is a need to take up a minimum pesticide treatment of 2 kg a.i of carbofuran or phorate. This cropping sequence has given 28 to 30 tons/hectare in PCN susceptible potatoes and 31 to 34 tons/hectare in resistant potatoes.

Root-knot Nematode

The root-knot nematodes, causing root galls are the most well known nematode parasites of plants. These are prevalent in all parts of the world, particularly in the sub-temperate, subtropical and tropical regions affecting almost all agricultural crops including potatoes.

Distribution

These nematodes have been recorded from all the potato growing countries of the world and have been considered as one of the most important pest of commercial crops next only to potato cyst nematodes. In India, Dr. M.J. Thirumalacher observed scab like warts on potato tubers from Simla during 1950 for the first time and since then it has been recorded on potato from all the potato growing states of the country. In 1889, Neal from Florida, USA recorded root-knot nematode on potato and designated it as

Anguillula arenaria. The nematode was also termed as *Heterodera radicicola,* till Goodey in 1932 preferred to group all root-knot causing nematodes as *H. marioni.* Later, the genus *Meloidogyne* was established by Chitwood in 1949, who described four most common and widely distributed, root-knot nematodes *viz.*, *M. incognita, M. javanica, M. hapla* and *M. arenaria.* Now about 65 species of *Melodiogyne* are described throughout the world. Among these about 10 species are reported on potato and the most important root-knot species are the ones described by Chitwood in 1949. The infection of *M. incognita* and *M. javanica* in potato is more damaging as they are able to infect potato tubers in addition to the roots. This infection causes warty outgrowths, which are typical in potato, which decreases the marketable value of the produce in addition to quantitative losses. Typically both species are wide spread throughout the country in all potato growing regions The most dominant species *M. incognita* occurs both in hills and plains while *M. javanica* infection to potato are confined mainly to mid hills and plains where the temperatures are fairly on higher side. The infection of *M. hapla* has been recorded on potato roots from hilly regions of Himachal Pradesh, Jammu and Kashmir, Uttar Pradesh and Tamil Nadu where milder climatic conditions prevailed.

Biology

The 2nd stage juveniles hatched out from the egg masses infect the young roots. This results in the formation of giant cells from which the nematodes extract nourishment from the plant cells. The giant cell and nematode development in the roots is associated with the formation of root-knot or galls. The female larvae enlarge gradually and undergo four molts to become pear shaped structure. The male nematodes retain their thread like appearance which come out freely from the root system and helps in fertilizing the eggs of the females. The female nematodes are sedentary in nature and deposit about 300 to 400 eggs into a gelatinous matrix, which is usually found adhering to the root galls. These eggs readily hatch and invade the fresh roots. At the time of tuber formation the freshly hatched larvae enter tubers. Thus many a times tubers developed typical root-knot symptoms in the stores, possibly because the larvae would have entered the tubers before suberisation at harvest and developed during storage.

Under Shimla conditions, *M. incognita* complete its life cycle in 25-30 days during April-September while in winter, *i.e.*, October-March it takes about 65 to 100 days. This has been mainly due to the temperature, which has also profound effect on the vertical distribution of larval populations in the soil. At Ranchi, a hilly tract, it took 28-35 days in June-July and 50-56 days in November-March months to complete one

generation. However, at Patna the life cycle was completed in 35 to 45 days during November to February. In the hilly regions two generations are generally completed by the time of tuber formation. Hence, tuber infestation is invariably observed even in low infested fields. In plains, tuber infestation could be low mainly because the crop duration is short and the newly emerging larvae mostly prefer the available fresh roots. This generally leads to the conclusion that the root-knot nematodes may be absent from a locality although they may be present on the roots. Further, hot summers in plains reduce the initial soil populations.

The eggs and larvae survive for more than 100 days even in the absence of hosts during summer months in Shimla hills. This could be the reason for higher initial inoculums, which could build up for subsequent tuber infestations. Experiments to study the effect of different levels per gram of soil resulted in 42.5 per cent yield reduction with 100 per cent tuber infestation. Nematode infested tubers on storing loose their weight more than uninfected tubers. Although post storage performance of infested tubers was normal, the number of sprouts produced was fewer compared to healthy tubers.

Interaction with Micro-organisms

The root-knot nematode infection has been found to predispose potato plants for infection by bacterium *Rolstonia solanecearum.* The incidence of brown rot in the presence of *M. incognita* was 86 per cent compared to 19.4 per cent with bacterium alone. The plants wilted much earlier in the presence of nematodes. Further, it was observed that whenever brown rot disease was prevalent in the North Western hills, the soils contained fairly heavy populations of root-knot larvae. The roots of such wilted plants exhibited prominent galling. It is suspected that the root-knot nematodes are helping in the spread and severity of brown rot disease in Sirmour district of Himachal Pradesh, Bhowali and surrounding areas of Kumaon hills in Uttar Pradesh and Bangalore and Kolar districts of Karnataka state.

Management

The basic principle of nematode control programme is to achieve increased good quality produce with reduced nematode populations. Last one hundred years of consistent efforts either to completely control or eradicate root-knot nematodes from soil rhizosphere revealed that man has to be content living with the pest and only try to minimise its ill effects. And thus the following management strategies are suggested for root-knot nematode management in potatoes.

Cultural Practices

(a) Deep ploughing and drying of soil in the summer months facilitates the drying of infective stage larvae thereby reducing initial inoculum in the soil.

(b) Adjustment of planting dates; Studies at Jalandhar have shown that planting in the 2nd week of October in autumn crop and early January in spring crop can limit the tuber infestation of the root-knot nematode. Under Shimla conditions early planting of potatoes, *i.e.*, during 3rd or 4th week of March reduces both root and tuber infestation without affecting the yield parameters.

(c) Burning of trash before taking up tuber planting helps in not only sterilising the soil but also enriches the soil. However, this method is practicable only in smaller holdings.

(d) Growing of trap crops like *Tagetes patula* and *T. erecta* (African marigolds) in between 2 or 3 rows of potato improves the crop performance and also reduces the root-knot nematode infestation. The root secretions from these plants are nematicidal and thereby the nematode populations are reduced to manageable levels.

(e) Though root-knot nematodes are polyphagous in nature with wide host range, there are a few crops like cereals and millets, which do not allow the infestation of *M. incognita.* Thus, crop rotation with a non-host like maize, wheat, beans, etc., reduces nematode infestations.

(f) Seed tubers from root-knot nematode infested fields should not be used. The movement of the soil and water from the infested fields should be avoided. The fields should be kept free from weeds since, root-knot nematodes have a wide host range and most of the weeds helps in the build up of the nematode. Thus, clean cultivation reduces the nematode infestation to a great extent.

Host Resistance

The most practicable approach for root-knot nematode management seems to be the use of host resistance. A large number of germplasm collections including tuber bearing wild *Solanum* species were screened for locating sources of resistance at Shimla. These studies showed that an inter varietal hybrid HC-294 possessed resistance to root-knot nematode since there was inhibition in the giant cell formation in the roots. Sources

of resistance were also available in few lines of *G. tuberosum* sub-species *andigena* and *S. vernei.* High degree of resistance was also found in *S. acaule, S. bulbocastanum, S. boliviense, S. acroscopicum, S. cardiophyllum, S. chacoense, S. gandarillassi, S. lignicaula, S. raphanifolium* and *S. spegazzinni.* Critical evaluation of commercial varieties and cultures have shown that the development and reproduction of root-knot nematode was lowest in several advanced hybrids and efforts are underway to incorporate these resistance into commercial varieties.

Biological Control

There have been extensive reports on the use of biotic agents such as fungi, bacteria, predacious nematodes and protozoans in the control of nematodes. However, efficient use of these biological phenomenons has not yet been fully exploited in root-knot nematode management. The fungus, *Paecilomyces lilacinus* and *Pochoia chlamydosporium* has been found to be most effective for managing *M. incognita* in potato while the bacterium *Bacillus penetrans* has also offered possibilities of bio-control. Endomychorrizal fungi such as *Glomus fasciculatus, G. mossae* and others have shown promise in reducing the root-knot nematode infestation and hence we can look forward for adopting suitable biological method of approach for the management of this nematode in potato.

Chemical Management

Earlier, application of DD @ 200 l/ha, EDB @ 90 l/ha and Nemagon @ 30 l/ha were found to be efficient in reducing root-knot nematode under Shimla conditions which were effective in the plains also. Due to the hazardous nature of these pesticides coupled with the difficulties in applying them under varying agricultural practices these are replaced by granular pesticides. Better management of the nematode has been achieved by applying carbofuran @ 2-3 kg a.i /ha or phorate @ 2 kg a.i /ha. The efficacy of these pesticides was more when they were applied in two equal split doses, *i.e.*, once at planting and another at ear thing time.

Integrated Approach

By practice, it has been observed that a single method of nematode control is uneconomical and it has been realised that proper blending of one or more methods has always been economical and effective in achieving better nematode management. This sort of approach should be aimed especially in potato particularly under Indian conditions since we have to keep in mind the various agro-ecological factors into account. Adopting

any single method of nematode control is bound to affect the ecological balance and hence various factors have to be carefully considered before advocating nematode management practices. However, by judicious application of above methods it is not difficult to manage root-knot nematode in potato for achieving higher production.

Other Nematodes

The potato tuber worm *Ditylenchus destructor* was reported from Shillong in 1961. The nematode was recovered on tubers, which had shown small greyish cracks with whitish glistening superficial tissues. Fortunately, this nematode has not been encountered again either in Shillong or anywhere else in India excepting in imported tubers and thus has been considered as one of the quarantine problems. Several other plant parasitic nematodes such as lesion, stunt, spiral, reni form nematodes are being constantly encountered during surveys of potato fields.

The pathogenicity of *Quinisulcius capitatus,* a stunt nematode frequently occurring in hilly tracts, was established on potato variety Kufri Iyoti at Shimla. The nematode build up ranged from 5 to 8 times at initial inoculum levels of 10 to 1000 at 45 days. Concomittant to the nematode build-up, plant characters such as shoot length, fresh and dry weights of shoot and rot reduced which affected the tuber production. The tuber reduction ranged from 14 to 29 per cent by weight, which was related to the reduction of dry weights of plant parts and was negatively correlated with nematode build-up index. The spiral nematode, *Helicotylenchus dihystera* was also pathogenic to potato accounting for 9-27 per cent yield reductions in 90 days with 2-4 times nematode build-up. Both these nematodes are commonly occurring in major potato growing belts of potato in Himachal Pradesh, Karnataka and Tamil Nadu and could be potential pests on a long run. Other parasitic nematodes constantly found in potato soils such as pin nematode *(Paratylenchus species),* reniform nematode *(Rotylenchulus reniformis),* lesion nematode *(Pratylenchus coffeae)* are already established pests to other crops and hence may also pose as plant protection problems but certainly not to the extent of either cyst nematode or root-knot nematode. The presence of virus transmitting nematode genera such as *Longidorus, Trichodorus* and *Xiphinema* with potato culture may be a constraint in disease free potato seed production.

Conclusions

Although 93 nematode species belonging to 40 genera are recorded to be associated with potato culture in India, not much has been done to understand their exact

involvement in potato production, excepting in case of root-knot and cyst nematodes. The detailed surveys conducted in North-western Himalayas have shown that root-knot nematode is the major pest of potato and is also invariably associated with the brown rot disease caused by *Rolstonia solanacearum.* The potato cyst nematode is restricted to hilly tracts of Tamil Nadu. Though it has been reported from neighbouring states of Karnataka and Kerala, the cysts were nonviable at the former state while in the later stat the potato cultivation is too low. However, there is a need for strengthening the domestic quarantine. Most of other nematodes are established pests in production of other crops. Hence, future lines of work on a national basis should be on the following lines:

Conduct organised surveys in potato growing areas to study the distribution of different plant parasitic nematodes and to identify the problematic areas for potato production: Identify the variations in root-knot nematodes and potato cyst nematodes to establish the species and pathotypes/races specific to localities; Estimate losses due to different nematodes and establish the economic threshold levels; Study the nematode survival, development and population dynamics in relation to different agronomic practices; Establish the interaction of these nematodes with other pathogenic fungi, bacteria and viruses and the predisposal factors, if any, Locate the sources of resistance in tuber bearing *Solanum* species and produce resistant varieties suitable to different regions. Evolve an effective and economic mode of nematode management by integrating different management strategies both for plains and hills; and set up an advisory service for proper nematode management in potato production.

References

Bhaskaran, A.R. 1971. Control of the potato golden nematode *(Heterodera rostochiensis* Woll) campaign in the Nilgiris, *Madras Agril. J.*, **58** (9 & 10): 800-808.

Gaur, P.C. 1973. Golden nematode in potato can be controlled, *Indian Farming*, **23** (1): 24-25.

Gill, J.S. 1974. Advances made in the potato nematology in India. *J. Indian Potato Assoc.* **1** (1-2): 51-55.

Howard. H.W. 1977. Report on the experiments at the Potato Experimental and Trial Centre, Ootacamund (Test Resistance of Material of Plant Breeding Institute, Cambridge to Nilgiri Populations of Potato Cyst Nematodes), Mimiograph, 17 pp.

Jones, F.G.W. 1961. Potato root eelworm *Heterodera rostochiensis,* in India. *Curr. Sci.*, **30** (5): 187.

Joseph, T.A. and Krishna Prasad, K.S. 2002. Kufri Giriraj: A high yielding late blight resistant potato variety for Nilgiris (Abst) presented in the National Seminar on "Changing Scenario in the production systems of Hill Horticultural Crops", Feb., 20-21, 2002, 195 pp.

Joseph, T.A., Krishna Prasad, K.S. and Latha, M. 2003. Breeding potato for combined resistance to late blight and potato cyst nematodes in Nilgiris. *J. Indian Potato Assoc.* **30** (1-2): 19-20.

Krishna Prasad, K.S. 1986. "Potato Nematodes." In: *Plant Parasitic Nematodes of India* (Gopal Swarup and D.R. Das Gupta Eds.). Indian Agricultural Research Institute, New Delhi, 497 pp.

Krishna Prasad, K.S. 2001. A sustainable Potato Cyst Nematode Management Practice for Nilgiri Hills. *J. Indian Potato Assoc.* **28** (10): 115-116.

Krishna Prasad, K.S. 2002. "Current Status of Potato Cyst Nematodes in India." In: *Centenary of Nematology in Tamil Nadu*, pp 51-55. Published by Centre for Plant Protection Studies, Tamil Nadu Agricultural University, Coimbatore-6410003, 137 pp.

Krishna Prasad, K.S. 2004. "Paradigms of Potato Cyst Nematode Research in India." In: National Symposium on Paradigms. In Nematological Research for Biodynamic Farming, 17-19, November, 2004 held at University of Agricultural Sciences, Bangalore.

Logiswaran, G. and Menon, P.P.V. 1965. Reports on the Golden Nematode *(H. rostochiensis)*— Survey in the Nilgiris, Madras State, Ootacamund Town. *Mad. Agric.* **1, 52** (11): 487-488.

Nirula, K.K. and Paharia, K.D. 1970. Role of root-knot nematodes in spread of brown rot in potatoes, *Indian Phytopath* **23** (1): 158-159.

Ramana, K.V. and Mohandas, 1988. Occurrence of potato cyst nematode *Globodera pallida* in Kerala. *Indian J. Nematol.* **18** (1): 141.

Ravichandran, G. Singh, D.B. and Krishna Prasad, K.S. 2001. Performance of Advance hybrid D/79-56 in Nilgiris. *Journal of Indian Potato Association*, **28** (1): 105-106.

Seshadri, A.R. 1978. "Chemical control of potato nematodes." In: *Developments in the Control of Nematode Pests of Potato*. Report of the 2nd Nematode Planning Confel Tence 1978. Lima, Peru. 13-17 November, 1978, pp. 173-87.

Seshadri, A.R. and Sivakumar, C.V. 1962. Golden nematode of potatoes *(Heterodera rostochiensis* Woll) threat to potato cultivation in the Nilgiris. *Madras Agric. J.*, **49** (9): 281-288.

Thangaraju, D. 1983. Distribution of potato cyst nematodes in Kodaikanal hills, Madurai district, Tamil Nadu. *Indian J. Nemat* **13** (2): 222-23.

❑❑❑

12

Role of Nematodes in Agro-ecosystem Management

A.K. Ganguly, Anju Kamra and N. Somasekhar

Introduction

Nematodes are a diverse group of microscopic round worms that are most ubiquitous and abundant multicellular animals living in soil. One square meter of soil may contain more than 30 billion nematodes. Nematode communities in soil are composed of a variety of trophic and ecological groups (Yeates *et al.,* 1993). The composition of nematode community varies depending on the plant species present and the geographic location. Relatively wide variation in trophic composition or abundance of nematodes within a site may also result from seasonal changes. Nematodes feed on a wide range of organisms and their food comes from entire microflora, microfauna and higher plants. The nematode communities in soil play an important role in regulating key ecological processes in soil food webs. In agro-ecosystems they are either beneficial or detrimental to crop growth. Therefore, understanding the roles of different groups of nematodes and their impact on crop production is essential for efficient management of agro-ecosystems. The different roles played by soil nematodes in agro-ecosystems are discussed below:

Roles of Nematodes in Agro-ecosystems

Nematodes as Herbivores

Plant parasitic nematodes are microscopic round worms that feed on plant parts mostly on roots. Nematode herbivores (plant parasitic nematodes) are of particular importance in agroecosystems because of their potential to damage the roots of crop plants. They are one of the most extensively studied group of soil organisms because of their economic importance can be distinguished by presence of a unique syringe/needle like structure called "stylet" in their mouth, which helps in puncturing and sucking of sap

from plant cells. Plant parasitic nematodes have been recognised as an important biotic constraint in crop production in many countries. Nematode feeding disturbs the water and nutrient absorption machinery in the root system, which in turn, results in stunted growth, chlorosis and wilting of plants even in the presence of optimum moisture and nutrients in the soil. Being obligate parasites, nematodes do not kill their hosts instantly, but debilitate them gradually host without producing any specific above-ground symptoms. Therefore, nematodes are aptly referred to as 'hidden enemies of the farmers'. Nematode infection also makes the plants vulnerable to secondary pathogens and abiotic stresses resulting in disease-complexes or syndromes (Hussey and McGuire, 1987).

It is estimated that nematodes cause an average annual yield loss of 12.30 per cent worldwide, which amounts to a monetary loss of about US$ 78.00 billions. In India, nematodes cause a yield loss of about 5 per cent in oil seeds, 8 per cent in cereals and pulses, 10 per cent in sugarcane and fruit crops, 12 per cent in vegetables. The total monetary loss due to nematodes in India has been estimated to be about Rs. 242 billion annually (Seshadri and Gaur, 1999). Nematode infection also makes the plants vulnerable to secondary pathogens and abiotic stresses resulting in disease-complexes or syndromes.

Nematodes as Biocontrol Agents

Entomopathogenic nematodes or insect parasitic nematodes are considered as beneficial nematodes in crop production because they help in biological control of the insect pests of crop plants (Kaya and Gaugler, 1993). The use of entomopathogenic nematodes to manage insect pests has gained popularity for several reasons. Like, development of resistance to certain pesticides, appearance of new pests, reduction of effectiveness of natural control agents (predators, parasites and pathogens) due to pesticide use, high cost of pesticides, and increased concern about pesticide safety and environmental quality are discouraging use of pesticides. These beneficial nematodes can form an important component of an integrated pest management (IPM) programme for ornamental crops and turf grasses. The two nematode families *viz*., Steinernematidae and Heterorhabditidae contain the insect parasitic nematode species. The most commonly used beneficial nematodes are *Steinernema carpocapsae, S. Feltiae, S. glaseri* and *H. bacteriophora.*

Entomopathogenic nematodes locate the insect host by detecting excretory products, carbon dioxide and temperature changes. Infective juvenile nematodes enter the insect host through the mouth, anus or breathing holes (spiracles). Heterorhabditid

nematodes can also pierce through the insect's body wall. The juvenile forms of nematode carry symbiotic bacteria *Xenorhabdus* or *Photorhabdus* in their pharynx and intestine. Once the bacteria are introduced into the insect host, death of the host usually occurs in 24 to 48 hours. As the bacteria enzymatically breaks down the internal structure of the insect, the Steinernematids develop into adult males and females, which mate within the insect's body cavity. Heterorhabditids produce hermaphroditic females. As nematodes grow, they feed on the insect tissue that has been broken down by the bacteria. Once their development has reached the third juvenile stage, the nematodes exit the remains of the insect body.

Entomopathogenic nematodes are beneficial for several reasons:

(1) They have a wide host range. The nematodes' nonspecific development, which does not rely on specific host nutrients, allows them to infect a large number of insect species.

(2) They kill their insect hosts within 48 hours, this is due to enzymes produced by the symbiotic bacteria.

(3) They can be grown on artificial media. This allows for mass production for large-scale use.

(4) The infective stages of these nematodes are durable. The nematodes can stay viable for months when stored at the proper temperature. Usually three months at a room temperature of 60° to 80°F and six months when refrigerated at 37° to 50°F.

(5) These nematodes compatible with various insecticides, herbicides and fertilizers.

(6) There is no evidence of natural or acquired resistance to the *Xenorhabdus* bacteria. Though there is no insect immunity to the bacteria, some insects, particularly beneficial insects are possibly less parasitised because nematodes are less likely to encounter beneficial insects, which are often very active and escape nematode penetration by quickly moving away.

(7) There is no evidence that parasitic nematodes or their symbiotic bacteria can develop in vertebrates.

These attributes make nematode use for insect pest control safe and environmentally friendly. The United States Environmental Protection Agency (EPA) has ruled that

nematodes are exempt from registration because they occur naturally and require no genetic modification by man.

Some predatory nematodes, particularly those belong to Mononchid and Dorylaimid groups predate on plant parasitic nematodes and thus have potential for biocontrol. However, little is known about their biology, ecology and field efficacy.

Nematodes as Regulators of Decomposition and Nutrient Cycling

Microbivorus free-living nematodes particularly the bacteriovorous and fungivorus species are beneficial to crop growth because they help in nutrient cycling in soil and thereby increase the nutrient availability to crop plants. Although nematodes constitute a relatively small portion of the soil biomass, their importance in regulating the soil environment must not be underestimated. It should be emphasised that nutrient cycling is a complex process involving many groups and species of fauna and microflora. Both nematodes and protozoa are important consumers of bacteria. The relative importance of these two groups may vary with soil type in that protozoans tend to be more abundant in fine-textured soils, where nematode activities may be limited by pore size. Bacterivorous nematodes are more capable of promptly migrating to substrates than protozoans and thus may be more important bacterial grazers in coarse-textured soils.

Nematodes are functional at more trophic levels than other organisms since they act as primary consumers (phytophagous), secondary consumers (bacteriophagous and myceliophgous), and tertiary consumers (omnivorous and predaceous). Nematodes play an important role in the decomposition of organic matter and mineralisation of plant nutrients. They also constitute an important energy pathway from primary production and detritus to higher trophic groups. The primary decomposition of organic matter is affected by bacteria and fungi, which, in turn, are grazed upon by microbivorous nematodes and by protozoa and other organisms. Because these nematodes consume bacteria and assimilate more nitrogen than needed, the excess nitrogen is excreted as ammonia.

Since herbivores and decomposers (bacterivores and fungivores) make up the most abundant nematode groups in most agroecosystems, energy flow through the soil nematode community takes two major pathways. Nematode herbivores function as primary consumers, removing energy directly from the plant whereas energy flows from plant to decomposers indirectly. Nematode decomposers do not feed directly on organic matter of plant origin, but on the bacteria and fungi, which break down this material. It

has been observed that the population density of bacteriovorous nematodes is high in places of high microbial activity or where the organic matter content is high.

Nematodes accelerate the decomposition process by dispersing relatively immobile microflora to new site and by their feeding, which regulates bacterial growth and decomposition. Over-grazing of bacteria is avoided as nematodes, in turn, are regulated by mites and other invertebrate predators. The increased decomposition rate resulting from nematode feeding increases the recycling and mineralisation of C and other elements and CO_2 evolution is a consequence of nematode activities (Abrams and Mitchell, 1980; Trofymow, *et 'al.*, 1983). Nematodes are particularly important in recycling N, which can become immobilised in bacterial populations during decomposition. Since nematodes have a higher C:N ratio (8:1 to 12:1) than their bacterial food source (3:1 to 4:1) their feeding results in the excretion of N, mostly as NH_3 (Ferris *et al.*, 1997). Numerous studies confirm the increase of NH and other inorganic N sources in soil with nematodes present, and increased N levels in plant tissue have resulted in some instances (Anderson.*et al.*, 1981; Ingham *et al.*, 1985). Nematodes also play an important role in the enhancement process of mineralisation.

Nematode as Promoters of Microbial Colonisation of Rhizosphere

The use of seed-applied beneficial soil bacteria as biofertilizers, biocontrol products or for bioremediation is an area of intense study. The rhizosphere favours bacterial growth and survival, and is the area of soil where biofertilizers and biofungicides are targeted. The role of nematodes in energy cycling and flow is significant because their consumption rates are high. Estimates of nematode consumption of root biomass from several studies indicated that it ranged from 34.8 to 57g m-1 (more than vertebrate herbivores). However, there are a few published studies on the influence of nematodes in root colonisation. The presence of nematodes in the rhizosphere has been shown to increase bacterial growth, stimulated by the products of incomplete digestion released by nematodes accompanied by increased nitrogen mineralisation. In addition, presence of nematodes in soils enhances bacterial activity by re-distributing plant symbionts and saprophytic bacteria (Cayrol *et al.*, 1987; Freckman, 1988). There has been limited work demonstrating that nematodes can act as vectors of plant pathogenic bacteria or rhizobium. These studies found that the nematodes distributed cells more evenly over the root surface, thus benefiting the plants. This area of research has not been further developed.

A range of specialist and generalist microorganism in the rhizosphere attack plant parasitic nematodes. Plants have a profound effect on the impact of this microflora on the regulation of nematode populations by influencing both the dynamics of the nematode host and the structure and dynamics of the community of antagonists and parasites in the rhizosphere (Kerry, 2000). In general, those organisms that have saprophytic phase in their life cycle are most affected by environmental conditions in the rhizosphere, but recorded its effects on obligate parasites. Although nematodes influence the colonisation of roots by pathogenic and beneficial microorganisms, little is known of such interactions with the natural enemies of nematodes in the rhizosphere. Since nematodes influence the quantity and quality of root exudates, they are likely to affect the physiology of those microorganism in the rhyzosphere. Such changes may be used as signals for nematode antagonists and parasites for successful biological control.

Soil Nematodes as Bioindicators of Agroecosystem Health

The abundance of soil organisms particularly key species has been proposed as a useful biological marker for ecosystem health. Nematodes are ubiquitous soil fauna that interact in ecosystems directly as herbivores on plants and indirectly as consumers of microflora and fauna, thus playing a significant role in regulating primary production, predation, decomposition of organic matter, and nutrient cycling. Several studies suggest that changes in nematode community structure may be useful as indicatores of environmental changes including anthropogenic disturbances. Use of nematodes as bioindicators of soil health and pollution is gaining importance in the recent years.

Nematodes possess many attributes that make them useful ecological indicators. Analyses to determine the effect of agricultural management practices on nematode community structure and function are generally based on nematode species, generic or trophic group abundance, diversity indices, and maturity indices. The assays involve survival and respiration rate of bacterivorous nematode relative to the concentration of toxicants/soil contaminants are some other measures to determine the ecosystem pollution. It has been observed that carnivorous, omnivorous and polyphagous nematodes are relatively sensitive to pentachlorophenol whereas bacterivores and fungivores are tolerant. Nematode community indices have been used for monitoring the changes in both natural and agroecosystems induced by a variety of disturbances. Nematode maturity index is being widely used as an indicator of soil ecosystem disturbance/ pollution in both agricultural and forests soils (Bangers, 1990). Significant differences

were found between annual and perennial systems in maturity indices for phytophagous nematodes and in the ratio of fungivorous and bacterivorous nematodes indicating that perennial crop sites may be better suited as reference points for using nematode as biological indicators.

Conclusions

Nematodes are the most abundant and ubiquitous metazoans in soil, which play a key role in the functioning of soil food webs. Nematodes interact in ecosystems directly as herbivores on plants and indirectly as consumers of microflora and fauna, thus play a significant role in regulating primary production, predation, energy transfer decomposition of organic matter, and nutrient cycling in soil ecosystems. Nematodes play varied roles in agroecosystems that are either beneficial or harmful to crop production. It is necessary to bring down the population of plant parasitic nematode to prevent valuable yield losses and at the same time it is also equally important to promote the populations of free-living and entomopathogenic forms that play a beneficial role. Further, changes in nematode community structure may be useful as indicators of environmental changes including anthropogenic disturbances. Nematodes possess many attributes that make them useful ecological indicators. Therefore, agroecosystem management methods must take into account both detrimental and beneficial effects of soil nematodes.

References

Abrams, B.I. and Mitchell, M.J. (1980). Role of Nematode Bacterial Interactions in Heterotrophic System with emphasis on Sewage Sludge Decomposition, *Oikos,* **35**: 404-410.

Anderson, R.V., Coleman, D.C., Cole, C.V. and Elliott, E.T. (1981). Effect of the Nematode *Acrobeloides* sp. and *Mesodiplogaster lheritieri* on Substrate Utilisation and Nitrogen and Phosphorus Mineralisation in Soil, *Ecology,* **62**: 549-555.

Bongers, T. (1990). The Maturity Index: An Ecological Measure of Environmental Disturbance based on Nematode Species Composition, *Oecologia,* **83**: 14-19.

Cayrol, J.C., Frankowski, J.P. and Quiles, C. (1987). *Cephalobus parvus* as a carrier of *Rhizobium japonicum* in field experiment on Soybean Culture, *Revue de Nematologie* **10**: 57-59.

Ferris, H., Venette, R.C. and Lau, S.S. (1997). Population Energetics of Bacterial feeding Nematodes: Carbon and Nitrogen Budgets, *Soil Biology and Biochemistry,* **29**: 1183-1194.

Freckman, D.W. (1988). Bacterivorous Nematodes and Organic Matter Decomposition, *Agriculture, Ecosystems and Environment,* **24**: 195-217.

Hussey, R.S. and McGuire, J.M. (1987). "Interactions with other Organisms," pp. 293-328. In: *Principles and Practice of Nematode Control in Crops* (Eds. R.H. Brown and B.R. Kerry), Academic Press.

Ingham, R.E., Trofymow, F.A., Ingham, E.R. and Coleman, D.C. (1985). Interaction of Bacteria, Fungi and their Nematode Grazers: Effect on Nutrient Cycling and Plant Growth, *Ecological Monographs,* **55** (1): 119-140.

Kaya, H.K. & Gaugler, R. (1993). Entomopathogenic Nematodes, *Annual Review of Entomology,* **38**: 181-206.

Kerry B.R. (2000). Rhizosphere Interaction and the Exploitation of Microbial Agents for the Biological Control of Plant Parasitic Nematodes, *Ann. Rev. Phytopathology*, **38**: 423-441.

Seshadri, A.R. and Gaur, H.S. (1999). "Integrated Nematode Management Approaches for Sustainable Agriculture." In: *Changing Scenerio in Farming Practices, Policies and Management.* Kushwaha, K.S. (Ed.), Farm Book Series, 296-319.

Somasekhar, N. (1998). "Soil Biodiversity: Role in Ecosystem Processes, Sustainable Crop Production and Economic Development," *Proceedings of Academy of Environmental Biology,* 7: 31-38.

Trofymow, J.A., Morley, C.R., Coleman, D.C. and Anderson, R.V. (1983). Mineralisation of Cellulose in the Presence of Chitin and Assemblages of Microflora and Fauna in Soil, *Oecologia (Berlin),* **60**: 103-110.

Yeates, G.W., Bongers, T., de Goede, R.G.M., Freckman, D.W. and Georgieva, S.S. (1993). Feeding Habits in Soil Nematode Families and Genera: An Outline for Soil Ecologists, *Journal of Nematology,* **25**: 315-331.

❑❑❑

13

Fungi for the Eco-friendly Management of Phytonematodes on Agricultural Crops and Its Future Perspectives

Archana Mittal

Introduction

Soil is a complex ecosystem comprising a wide variety of life forms often developing symbiotic, synergistic or antagonistic relationships among themselves. Fungi, bacteria and phytonematodes constitute the significant component of soil ecosystem. Plant-parasitic or phytonematodes often cause plant diseases by themselves, resulting in significant losses in crop yield and quality. However, uneven growth, stunting, chlorosis and poor quality and quantity of yield are general symptoms of severe infection and damage caused by plant-parasitic nematodes. Nevertheless. plant-parasitic nematodes are only one component of the rhizosphere microbial community of crop plants, which also includes pathogenic and nonpathogenic fungi, bacteria, microarthropods and other organisms. Among the plant-parasitic nematodes, root-knot nematodes belonging to the genus *Meloidogyne* are regarded as serious pests constituting an important major limiting factor in the production of agricultural and horticultural crops. The root-knot nematodes known for more than a century have attracted attention of most nematologists and plant pathologists all over the world. Though they attack almost every type of crop, causing considerable losses of yield and affecting the quality of the produce, vegetable crops mostly suffer greatest damage. Bhatti and Jain (1977) found an estimated loss due to *M.incognita* throughout India in tomato is 46.2 per cent. Thus, various measures that have been in use for control of phytonematode in the past are chemical, physical, regulatory, use of host resistance and biological methods.

A number of chemicals both soil fumigants and systemic were successfully used for the management of plant-parasitic nematodes. However, most of the chemicals are banned and out of market due to their toxic effect on beneficial flora and fauna including

man. They cause pollution hazards and their influence on non-target organisms have caused ecological imbalance which are sometimes difficult to be restored. Search for some alternative methods of nematode control thus received greater attention. In addition to the safety problems of pesticides, new crop protection technique, the IPM or Integrated Pest Management methods including organic amendments, fungal bioagents, botanical antagonists and reduced dose of nematicides has been proposed in order to reduce the effects of agrochemicals on the ecosystem. This is intended to maintain pest density at economic threshold injury level using a combination of various pest control methods.

The modification of soil environment in a manner which would reduce the population of harmful microorganisms and at the same time increase the fertility of the soil would be more beneficial approach to a farmer better known as eco-friendly management. The combinations of chemical, cultural, biological and genetic control measures under integrated pest management approach can be expected to be effective, economical and eco-friendly. Attempts are in progress in India to try fungal bioagents with very low dose of nematicides or organic amendments etc. as a part of integrated approach for the management of plant parasitic nematodes. Thus, effective control of plant-parasitic nematodes involved in disease complexes has substantiated their significant role in such diseases and demonstrated the need for the integrated nematode management root diseases in general. The first report on fungal biocontrol agents was suggested by Lohde (1874) with observations on the endoparasite, *Harposporium anguillulae* in Germany. Kuhn (1877) reported *Catenaria auxillaris* in the females of beet cyst nematode, *Heterodera schachtii*. Contributions of Goswami and Rumpenhorst (1978), Kerry (1980), Khan (1990) and Leiz *et al.*, (1992) clearly showed that the biocontrol agents, particularly the nematode destroying fungi are common and abundant in both natural and agricultural soil as also in all kinds of decaying organic materials.

Fungal bioagents of plant-parasitic nematodes are grouped as:

A. Predaceous or trapping fungi

B. Endozoic or endoparasitic fungi

C. Egg parasitic or opportunisitic fungi

A. Predaceous or nematode trapping ones mostly belong to the order Zoopagles (Zygomycetes) and from order Moniliales (Deuteromycetes) which capture nematodes by various devices as (a) Sticky, and (b) mechanical traps. Sticky traps are of 3 types: (1) sticky branches *e.g.*, *Dactylella lobata,* (2) sticky network *e.g.*, *Arthrobotrys oligospora,* and (3) sticky knobs *e.g.*, *Dactylella*

ellipspora while the mechanical traps are of 2 types: a) non-constricting rings *e.g., Dactylaria candida* and b) constricting rings *e.g., Dactylella bembicodes.* Sucrose decomposition in the soil stimulates and increase in both the population of free living nematodes and the activity of indegeous nematodes trapping fungi and soil conditions *viz.*, pH, temperature, moisture and availability of nutrients (Mankau,1968). The use of nematophagous fungi as bioagents of nematodes was shown by Upadhyay and Dwivedi (1988). Nakasono and Gaspard (1991) determined the effectiveness of two nematophagous fungi, A. dactyloides and Dactylella haptotyla for root-knot and free living nematodes. The nematophagous fungus, A. oligospora produces proteases in liquid culture that is involved in the infection and immobilation of nematodes (Tunlid and Jansson, 1991).

B. Endozoic or endoparasitic fungi which are natural enemies of plant-parasitic nematodes produce either simple spores or flagellate spores as infectious agents and instead of producing hyphal development outside the body of the host, germination of spores are within the nematode body. Till they make contact with the host the spores remain viable but dormant. Simple spores are ingested by the nematodes, reach the oesophagus/buccal cavity where they germinate, penetrate the oesophagus and colonise the body cavity *e.g., Harposporium anguillulae.* The sticky spores stick to the nematode at any point but mostly cause infection in the head region. They germinate, penetrate directly through the nematode cuticle and produce infective hyphae within the body cavity, *e.g., Meria coniospora, Nematoctonus bisporus.* The flagellate spores stick to the nematode and encyst before germination, penetration and colonisation of the host *Catenaria unguillulae, C. vermicola, Harposporium anguillulae* among the fungi was to be found effective in checking nematode population (Lodhe,1874). *Nematophthora gynophyla* in addition to *Globodera rostochiensis* and *Heterodera avenae* also parasitised females of *H. trifolii, H. schachtii,* etc. (Kerry and Crump,1977). *In vitro* observations on the infection of *Meloidogyne incognita* eggs by *C. anguillulae* was reported by Wyss *et al.* (1992) whose embryos were observed to be killed within a few minutes within mass aggregation and encystment of flagellate spores of fungus. However, the obligate nature of both predaceous and endozoic fungi difficulty in mass production and inability to establishment in soil are the characteristic that put a serious question mark for their candidacy as biocontrol agents.

Fungal Parasities or Opportunistic Fungi of Eggs/cysts:

Several soil fungi found to be parasitic on eggs of plant parasitic nematodes colonise the reproductive structures of the nematodes particularly *Meloidogyne. Heterodera* and *Globodera* species whose sedentary stages are most vulnerable to fungal attack.. These fungi occur in genera, *Paecilomyces, Verticillium, Fusarium, Phoma, Gliocladium* etc. These opportunistic fungi attack nematode eggs and/or cysts of the group *Heteroderidae* and those deposited in gelatinous matrix.. Plant parasitic nematodes that become sedentary upon their maturity and have oviposition nature are considered to be the most vulnerable to attack to these fungi. As soon as these fungi contact egg masses or cysts, they rapidly grow and colonise these eggs that are in early embryonic developmental stages. Arai *et al.* (1973) isolated peptide antibiotics lencinostatin, lilacinin from *Penicillium lilacinum. P.lilacinus* exhibits chitinase (Okafor, 1967; Gintis, *et al.*, 1983) and proteolytic activity (Endreeva *et al.*, 1972). It also produces a peptidal antibiotic P168 which exhibited wide range of toxicity on fungi, yeast and gram-positive bacteria (Isogai *et al.*, 1980a, 1980b, 1981).

The embryonated eggs treated with culture filtrates showed morphological changes in eggs and within 2-4 days, development of eggs stopped, embryo disintegrated and vacuole formed (Fitters *et al.*, 1993). The death of mature eggs, colonised internally was due to fungal metabolites (Carneiro and Gomes,1993). P.lilacinus can grow well in temperature ranges between 15°C and 30°C which is similar to its hosts. It can also survive well in wide range of soil pH, thus showing its competitive nature in most agricultural soils (Jatala,1986). This fungus is reported to be compatible with many fungicides and nematicides. (Davide and Batino, 1985). *P. lilacinus* showed growth at 3.0 to 11.0 while optimum mycelial growth occurred at pH 6.0 to 9.0 and sporulated at pH 4.0 to 6.0. The good sporulation was observed at 30°C and mycelial growth inhibited at 10°C and 40°C. The alternate light and darkness provided better fungal growth (Villanueva and Davide, 1984). Cabanillas *et al.* (1989b) recorded maximum fungal growth of *P.lilacinus* between the temperature ranges of 24°C and 30°C and least was at 12°C and 36°C. The effect of soil temperature on fungal parasitism has not been studied so far. However, it has significant impact on the survival and biocontrol activity of *P.lilacinus* isolates (Cabanillas *et al.*, 1989b). Fioretto and Villacorta (1989) found that optimum temperature for *P.lilacinus* growth was 24°C to 25°C but biostatic at 30%C and 35°C. The lower threshold

temperature was –10.9°C for development of the fungus. This attribute could be useful for storage of *P.lilacinus*. Liu *et al.* (1995) observed that among the 20 isolates of *P.lilacinus*, optimum temperature (25°C to 30°C) requirement for growth and sporulation was not different among the isolates. Certain chemicals *viz.*, ethoprophos, fenamiphos, aldicarb, oxamyl and carbofuran were reported to toxic to *P.lilacinus* in PDA-culture (Equiguren-Carrion, 1995). Amoncho and Sasser (1995) found that benomyl stopped the *P.lilacinus* growth and chlorothalonil, cpatan and PCNB suppressed the radial growth but fenaminosulf slightly enhanced the fungal growth.

The biocontrol potential of the fungus, *V.chlamydosporium* for root-knot nematodes has been reviewed by Leij and Kerry (1991). The fungus required some external nutrient for its establishment in soil. The colonisation of nematode egg masses depended on fungal inoculum and on galling caused by nematodes (Leij *et al.*, 1992). The efficiency of *P.lilacinus* in controlling *M.incognita* and *G.pallida* was demonstrated by Franco *et al.*, (1981). The eggs were deformed by the fungus with the help of toxic metabolites. Mature females of root-knot nematodes were usually penetrated by the fungus through the anus or vulva while cysts of *G.pallida* through the vulva and exposed or broken neck region (Jatala, 1986). They reported that hyphal penetration of egg shells were brought about by mechanical pressure and/or enzymatic activity. Rate of fungal penetration into egg shell of *Meloidogyne* eggs is faster than *Globodera* where the egg shells show more complexity (Jatala, 1985). Work has been carried out for managing root-knot nematode infecting vegetables in India (Pandey and Trivedi, 1991). Khan and Hussain (1986) reported that females, eggs and juveniles of *M.incognita* were infected by *Fusarium solani.*

Methods for the Isolation of Fungal Bioagents

Stirling and White (1982) used baiting technique to isolate obligate parasites in which usually a large number of susceptible nematodes from laboratory culture are added to soil and then extracted after a period of incubation and assessed for infection. The egg-parasitic fungi which are consistently associated with the eggmasses of root-knot nematodes are isolated, subcultured and attempted for mass culture after testing their potentiality as biocontrol agent through *in vitro* studies and pot expts. But, for the isolation of facultative parasites sprinkling techniques is suitable or in some cases selective media *i.e.*, carrot extract, Potato Dextrose agar, etc. can be used.

Maintenance of Stock Culture

The culture of toxic and egg-parasitic fungi are maintained on Potato Dextrose Agar medium slants in test tubes and Potato dextrose broth in 250ml conical flasks after incubating in BOD at 25+2°C for 10-15 days. Spores of source inoculum containing same medium serves as a seed culture for further mass multiplication. The colony forming units per ml is generally in the range of 3x10 to 3x10.

Mass Culturing

Mass culturing of some potential fungal bioagents *viz. A. niger, T.viride, A.fumigatus, A. terreus, P.lilacinus, Acremonium strichtum* and some others are being undertaken on large scale for the control of root-knot nematodes. This is done through a combination of substrates, molasses/sugar and water. Saw dust is used as a carrier material after oven heating at 125+5°C overnight. The suitable medium comprises of leaf powder (parthenium, soobabool, castor, jamun, etc.) neem, cotton seed and/or karnaj cake. These are easy to prepare and also very economical mediums. The carrier material would help in adhering the fungal bioagents to the seeds, to maintain the viability of the cells, to dilute the culture and also to protect (partly) the bioagents against desiccation. Mass culturing is done on large scale in autoclavable polyethylene bags. The various constituents used for this purpose are—neem/karanj/cotton/castor seed cake (15g), parthenium/soobabool leaf powder (15g), Molasses/sugar (10ml or 10g) and water (50ml). The above ingredients are mixed together and put into autoclavable polybags having 50-75 μm thickness, low density and 6"x 6" in size and allowed to soak for 48 hours. These polybags are used for packing of the inoculants. These bags were sealed and sterilised in an autoclave at 121°C for 30 minutes at 15lb pressure. The medium in each bag was inoculated with 15 days old respective fungus after desealing the polybags in lamina flow. The bags were immediately sealed with the flame under aseptic condition and kept for growth in a BOD incubator at 25+2°C for 15 days which would be ready for application. The approximate weight of the bag along with its above content is 100g. The cost of each packet is approximately between Rs. 5.00 and 6.00. The fungal bioagent developed by this method would be easy to use, economical, non-hazardous/non-pollutant, readily available and could be used by the farmers either by dissemminating in nursery beds or given as seed treatment and/or root dip treatment. This could also be used as spot application at the time of sowing in an infested field.

Kerry (1987) found that applying bioagent with the planting material would be particularly useful for field crops where large areas have to be treated. These techniques

could be improved upon to introduce this type of fungi through seed coats in large areas using minimum quantity of the carrier material. Backman and Rodriguez-kabana (1975) found that treatment with a biocontrol agent in excess of 200kg per hectare should be avoided to keep costs of production, storage and application at an economic level. Low costs efficacy, compatibility with existing farm practices and safety are important in determining the acceptance of biological control products by the growers. It would be advisable to apply some potential fungal bioagent in combination with locally available and less costly plant and animal wastes. Bhattacharya and Goswami (1988) have already carried out work in this direction by combining oilcakes and nematicide for reducing nematode population. .

Mass Production of *P. lilacinus*

Biocontrol programmes include enhancement of naturally occurring antagonists or augmentation of their activity by introducing other antagonist for suppression of target pathogen or pest of crops. Such augmentation could be achieved through release of mass produced parasites or predator (Knipling, 1979). Sharma and Trivedi (1987) observed maximum growth of *P.lilacinus* on sesame cake followed by cotton, mustard and groundnut cake. Among the waste materials, mungbean husk exhibited maximum growth followed by cotton seed, guar powder, gram powder and rice husks. The oilcakes had additive effect because of their nematotoxic properties. Bansal *et al.* (1988) evaluated agro-industrial wastes for mass production of *P.lilacinus*. The rice husk produced of *P.lilacinus*. The rice husk produced least spores while the wheat bran provided maximum spores which was comparable with rice grain. The sporulation was found enhanced in rice husk and rice bran with addition of molasses amended with nitrogen and phosphorus.

Zaki and Bhatti (1988) recorded higher spore counts (55.5 x 10/g) in neem leaves and concluded that incorporation of neem leaves infested with fungus may have synergistic or additive effect on nematode population. Mani and Anandam (1989) also evaluated plant leaves, oil cakes and agro-industrial wastes as substrate material for mass production of *P.lilacinus*. The leaves of *Leucaena leucocephala* and neem were found suitable and supported higher spore load. Mani *et al.* (1989) observed that wheat, bajra, jowar and rice as substrate media were suitable for mass production of *P. lilacinus*. *T.semipenetrans* population was markedly decreased with increasing the level of fungal inoculum and the spore suspension was found more effective than fungus infested wheat grains.

Vicente *et al.* (1989) compared among the available rice grains for mass production of *P.lilacinus* and found that pounded commercial rice and unpounded ground

rice were most suitable on the basis of spore count while unpounded commercial rice had least spore load. Zaki and Bhatti (1991) found that *P.lilacinus* sporulated profusely on maize, gram, oats, rice and wheat grains. The maximum number of spores/g was observed on rice (52.8x10) followed by gram (24.5 x 10). The fungus grown on gram seed was the most effective against *M. javanica* infecting tomato plants. The reduction of gall index (78.6%), population of *M.javanica* (94.2%) and higher percentage of egg destruction were observed.

Patel *et al.* (1991) tested various organic amendments for their effects on growth and sporulation of *P. lilacinus* and found that karanj, neem and mahua cakes were most effective while pressmud and FYM were least effective. Bansal *et al.* (1992) observed that wood charcoal was a good carrier of *P. lilacinus* for applying in the field. The carrier material in low-density polyethylene pouch could support up to 10 spores/g for at least six months. The spore viability in charcoal packets was not affected by constant temperature 28°C and ambient temperature 14°C to 19°C or even under aerated/or unaerated condition.

Mode of Action

The combined effect of both fungal bioagents *T.viride* and *P.lilacinus* for the control of root-knot nematodes is mainly based on the toxic effect of former followed by the egg parasitic ability of the later. Thus, a reasonable number of the infective second stage juveniles occurring in the soil around the root zone of affected plants would be reduced. The remaining juveniles expected to be less in number as also possessing lower rate of infectivity due to the toxic effect of *T.viride* would invade the roots. Out of these reduced number of juveniles which in turn would invade the fresh egg masses, very few would develop into adult which are attacked by *P.lilacinus* resulting in the production of mostly unviable eggs. Many of the eggs due to this fungus are found empty.

Method of Application (with dose)

For transplantable crops *viz.*, tomato, brinjal, chilli, etc. after deep ploughing treat the nursery bed with organic amendment like oilseed cakes etc. 10 days before sowing. At the same time, treat the bed with both the packets along with 400g/packet of the carrier material *i.e.* saw dust. Before transplanting the seedlings, a root-dip treatment may be given for 5 minutes in dense conidial suspension of fungal bioagents. Spot treatment may also be given after 20-25 days of transplantation.

The dose is 10 packets (5 each) for 3x3 square meter nursery beds. But, for directly seeded crops like cucurbits, bhindi and pulses apply at the time of sowing with a

sticky substance like gum arabica etc. along with appropriate amount of carrier material (saw dust) @ 400g/packet. In these spot treatment with both after 20-25 days of sowing is given at @ 2 packets of each for 1kg seed.

Walia and Bansal (1992) found that to initiate significant suppression of *M. javanica* population, a minimum of 10 spores was required. However, the fungus failed to reduce nematode population below the damaging level even at the highest level (10) of fungal inoculum. Zaki and Maqbool (1991) obtained most effective control of *M. javanica* chickpea with application of *P.lilacinus* (2g/pot) one week before nematode inoculation. Zaki (1994b) suggested that 4g of gram infested *P.lilacinus* per kg soil was optimum for significant reduction of gall index, and *M.javanica* population in tomato plants. The egg infection and destruction were 58% and 66% respectively. Jonathan *et al.* (1995) found greater reduction of *M.incognita* population on Piper betle with application of *P.lilacinus* infested rice substrate @ 8g/kg soil. Patel *et al.* (1995) observed that soil application of *P.lilacinus* at 3% to 5% (w/w) on neem cake was effective against *M.javanica* infecting groundnut whereas seed treatment was ineffective. Davide and Zorilla (1995a) found that tuber-dip and soil-mix method of application of *P.lilacinus* were equally effective against *G.rostochiensis* on potato and their combined application enhanced nematode control efficacy.

Longevity and Shelf Life (storage)

The packets containing bioagents should be stored in dry, cool and shady places away from direct sunlight and heat. The viability of bioagents can decrease with rise of temperature greater than 35°C but under controlled condition (cold storage conditions or 5°C), viability can be maintained upto one year.

Advantages

It protects the crop from root-knot damage, disesae-complexes caused by root-knot nematode and some pathogenic fungi, as oilseed cake used in the medium of mass culture is also fungicidal. It is environmentally safe, with no pollution, much cheaper than a standard nematicide or other costly affairs and results in disease free plants, much healthier and thus adds to the yield. However, all the materials used in preparing packets are natural products, ecofriendly, the packets are safe for use by farmers with zero risk.

Oil Cakes and Organic Amendments for the Management of Plant-parasitic Nematodes

In India exhaustive work on the application of oil-cakes for the control of plant parasitic nematodes has been done. The first investigation on the control of root-knot

nematode with Karanj (*Pongamia glabra*) oil-seed cake was carried out by Singh and Sitaramaiah in 1966 on tomato. This was followed by effect of oil-cake amended soil of karanj, neem, mustard etc. against *M.incognita* on tomato. Desai *et al.* (1972) used marotti, neem, karanj and groundnut oil-seed cakes against root-knot on tobacco while Goswami and Vijayalakshmi (1981) carrying out an experiment to study the efficacy of 10 dried plant materials and 5 oil-seed cakes. In case of oilcakes sal, neem and karanj reduced the galls as well as nematode populations in soil. Goswami *et al.* (1989) reported maximum suppression of *M.incognita* population in cowpea roots treated with karanj and Hind-O-meal followed by carbofuran treated plants while in 1990, Darekar *et al.* testing neem, karanj, mahua and castor oil-seed cakes for the control of *M.incognita* population in tomato found neem and karanj to be most effective. Rao and Goswami (1996) studied the comparative efficacy of organic amendments, an inorganic amendment (ABCD) and carbofuran against root-knot nematode *M.incognita* and observed reduction in nematode development caused by *M.incognita* with the use of mustard followed by neem, carbofuran and ABCD. Plant growth characters were greatly improved in mustard and neem followed by karanj, mahua and ABCD. In recent years research is also under progress on the integration of oil-seed cakes with nematicides in reduced doses in both directly seeded as also in transplantable crops. Sosamma *et al.* (1994) reported that application of *P.lilacinus* 25 days before *Radoholus similis* inoculation in Piper beetle was effective in reducing nematode damage. The neem cake extracts (5% and 10%) were found very useful carrier for *P.lilacinus* and it effectively controlled *M. incognita* on brinjal (Rao and Reddy, 1994).

Role of Soil Mycoflora for the Management of Plant-parasitic Nematodes

Work done by several researchers have proved that some micro-organisms, especially fungi produced metabolites that are toxic to root-knot nematodes. Thus, Mankau in 1968 reported nematicidal activity of culture filtrates of *Aspergillus niger.* Singh and Sitaramaiah in the same year showed parasitisation of *M. javanica* by *Curvularia* species. Later, Singh *et al.* (1983) reported that culture filtrates of *Aspergillus niger, Curvularia lunata, Trichoderma viride* and *T. lignorum* obtained from rhizosphere of tomato plants proved to be nematoxic and inhibited hatching of *M. incognita* larvae. Tabreiz *et al.* (1884) studied the effect of culture filtrates of 8 species of *Aspergillus* on hatching and mortality of *M. incognita* out of which *A. niger, A. terreus* and *A. fumigatus* were more toxic than the other species. Sharma and Saxena (1992) observed that culture filtrates of *Rhizoctonia solani* and *Trichoderma viride* adversely influenced hatching of *M. incognita* larvae. Both fungus showed relatively more toxicity. Khan *et al.* (1988)

observed inhibition of hatching of *M. incognita* juveniles at different concentrations of fungal culture filtrates and complete inhibition was recorded at 50% and 100% concentrations. The filtrates suppressed the root galling of tomato plants caused by *M. incognita*. Zuckerman *et al.* (1994) reported that molecules in the culture filtrate of *A. niger* larger than 8000 MW killed *Caenorhabditis elegans* within 10 min and *M. incognita* second stage larvae in 60 min. Culture filtrate retained nematicidal activity against both the species after boiling for 5 min also suggesting the heat stability of the toxin principle. It was found that when bioassay and HPLC analysis combined, 8-day old culture filtrate showed nematicidal activity at mean oxalic acid residues of 6.1g/lit and citric acid of 0.9g/lit.

Chawla and Goswami (1998) in an vitro evaluation of undiluted *A.niger* culture filtrate, demonstrated the complete suppression of larval emergence for the first three days and the total death of juveniles within 24 hrs in case of *M. incognita*. Siddiqui and Mahmood (1995) while working on the management of root-rot disease of chickpea, demonstrated than filtrate of *A. niger* markedly reduced number of nematode in the soil which in turn was attributed to the concentration of oxailc acid produced by the fungus. Moreover, autoclaved culture filtrate also immobilised the nematodes, the heat stability of toxin principle.

Cayrol *et al.* (1989) reported nematicidal properties of culture filtrates of *P.lilacinus*. The toxins production were different on different media and their effect differed on various nematode species. The mechanism of toxic activity was considered to be neurotropic. Acetic acid was identified from culture filtrates of *P.lilacinus* and it affected the movement of nematode juveniles (Djian *et al.*, 1991). Caroppo *et al.* (1990) found ovicidal activity of *P.lilacinus, P. maraquandi, P.variotii* and *P.coleus* against M.incognita. The culture broths of these fungi reduced 78 to 93% egg hatching under exercised root culture of tomato. Khan and Khan (1992) observed that concentration of culture filtrates of *P. lilacinus* had direct relation to the inhibition of hatching and percentage mortality of *M. incognita*. Siddiqui and Hussain (1991) tested that culture filtrate of *P.lilacinus* was quite effective against *M. incognita* and *Macrophomina phaseolina* while Zaki (1994a) reported that culture filtrate of *P.lilacinus* had immobilising effect on *M. javanica* and inhibited hatching of eggs. Oduor and Waudo (1995) also reported that *P.lilacinus, P.herbarum* and *Fusarium oxysporum* had suppressive effect on hatching of *Meloidogyne* spp. but hatched juveniles were not parasitised. A reduced hatching ranging between 21% and 56% was observed in *Heterodera glycines* by *P.lilacinus* (Chen-Sen Yu *et al.*, 1996).

Experimental results from the infested fields in different countries have indicated that *P.lilacinus* effectively controls *M.incognita* and even better than number of commonly used nematicides (Candanedo *et al.*, 1983; Jatala, 1983). The successful field results of *P.lilacinus* for biocontrol of *Tylenchulus semipenetrans* on oranges in Peru have been reported. The fungus reduced *T. semipenetrans* populations to relatively lower levels than nematicides tested. There was significant increase in root development, plant growth and fruit diameter with the inoculation of *P.lilacinus* (Jatala, 1983). The effect of single and multiple application of *P.lilacinus* against *M. incognita* under field trials revealed that only one inoculation was sufficient to establish it and to get substantial degree of nematode control (Jatala *et al.*, 1981). However, Cabanillas and Barker (1989) indicated that effective biocontrol for *M. incognita* required more than one application and at proper time.

Davide and Zorilla (1985) while investigating the biocontrol potential of *P.lilacinus* against *M.incognita* on okra found the fungus to be quite effective and economically better than nematicides. According to Shahzad and Ghaffar (1987) carbofuran @ 1kg a.i./ha was less effective than *P.lilacinus* against *M.incognita*. This fungus also effectively controlled nematodes on okra and mung in subsequent seasons but nematicide was no longer effective. Similarly, in the fungus treated plots, higher yields were recorded than carbofuran @ 2.5 kg a.i./ha. The efficacy of *P. lilacinus* had been comparable to that of most commonly used nematicides (Jatala, 1985). The fungus, *P.lilacinus* reduced the soil population of *M. incognita* by 66 per cent to 77 per cent whereas isazophos reduced it by 89% (Davide and Zorilla, 1986).

Dube and Smart (1987) obtained higher crop yields and reduced *M. incognita* population when *P. lilacinus* and *Pasteuria penetrans* were applied together in field microplots. Maheshwari and Mani (1988) also found that simultaneous inoculation of *P.lilacinus* and *Pasteuria penetrans* were more effective and capable of significant reduction of soil population of *M. javanica.* The introduction of *P.lilacinus* 10 days before at planting of tomato resulted in great protection against *M. incognita* and mid-season inoculation also provided higher percentage of egg mass infection (Cabanillas and Braker, 1989). Khan and Esfahani (1990) found that *P.lilacinus* was more effective for controlling *M.javanica* infecting tomato when fungus was added prior to nematode or simultaneous inoculation. A great number of nematode eggs were infested, juvenile development inhibited, eggs devoid of juveniles and only filled with fungal mycelium. The developed juveniles were also found attacked and mycelial growth over their bodies were observed.

Walia *et al.* (1991) reported that application of *P.lilacinus* through wheat bran was better than carbofuran @ 1kg a.i./ha in gall reduction on okra plants infected with *M. javanica.* Vicente *et al.* (1991) evaluated *P.lilacinus* for controlling *M. incognita* and *Rotylenchulus reniformis* in infested fields of watermelon. The application of this fungus two weeks before planting was better than carbofuran or fenamiphos for controlling nematodes. Vicente and Acosta (1992) conducted field trial to compare the effect of *P.lilacinus* and carbofuran against *M.incognita* and *R.reniformis* on pepper. The inoculation of fungus one week before planting and application of carbofuran were equally effective for significant nematode reduction and obtained heavier fruit yield of pepper. Oduor *et al.* (1996) observed plant performance and low gall index with the application of *P.lilacinus* in combination with aldicarb or nematicidal plants.

Indirect Influence of Fungi from Organic Additives

Researches have shown that the organic matter in the soil, in addition to the increased microbial activities also cause enhanced enzymatic action. Meshram and Goswami (1989) recorded that the fungal extracts of the dominant fungi isolated from soil amended with mustard and karanj oil seed cakes showed strong larvicidal effect with inhibition of larval emergence. A collagenolytic fungus, *Cunninghamella elegans* reduced root galling, egg hatching and immobilised second stage juveniles of *M.javanica* in tomato plants when collagen was used as soil amendment (Galper *et al.*, 1991). The different animal manures were evaluated and compared with wheat grain medium for mass production, storage and application of some nematode egg parasitic fungi (Abu-Laban and Saleh, 1992). Mycelial growth indices of *Acremonium sclerotignum, Fusarium solani, F. oxysporum, Microascus triganosporus, P.lilacinus* and *Phoma laveilei* on animal manures were similar or higher than on wheat grains. The fungi were effective in reducing root galling on glasshouse tomato plants caused by *M. javanica.*

VAM and Organic Amendment in the Management of Plant-parasitic Nematode

The effect of *Calotropis procera* and *G.fasciculatum* for the management of *M.incognita* in tomato was studied by Rao *et al.* (1996). Significant reduction of galls, eggs/egg mass observed in interactive effect of these components. Higher colonisation of mycorrhiza in root of tomato inoculated with *G.fasciculatum* and *Calotropis* leaf was observed..Gaonkar and Sreenivasan (1994) observed a positive influence of locally available organic amendments on proliferation of *G.fasciculatum.* Devi and Goswami (1992) and later Bhagawati *et al.* (2000) demonstrated that both *G.fasciculatum* in case of cowpea while *G.etunicatum* in tomato respectively together with mustard cake helped in

reducing the disease severity caused by *M.incognita* fungus complex in both the above hosts. They observed that the pre-establishment of VAM fungus checked the entry of *M.incognita* larvae as also colonisation of pathogenic fungi *Macrophomina phaseolina* and *F.oxysporum f.sp.lycopersici* respectively.

Combination of Fungal Bioagents

In recent years with the development of a number of fungal bioagents isolated from egg masses of *M.incognita* infecting vegetables and categorisation of two types *i.e,* (a) toxic, and (b) egg parasitic ones. Attempts have been to test the performance of two types alone as well as together. The combined effect of a toxic bioagent *Aspergillus terreus* with an egg parasitic one, *Paecilomyces lilacinus* showed better performance in reducing nematode population with improved plant health of tomato than when either of the above fungi was used alone (Goswami and Sharma, 1999). Similar finding is observed by Goswami and Mittal (2000) when *A fumigatus* was applied to the soil along with *Trichoderma viride* on tomato infested with *M.incognita*. Here, in addition to the reduction in nematode population plant growth was also observed to be promisingly improved in both the above investigations and the mode of action is explained.

Commercialisation of Nematophagous Fungi

In France two commercial agents, Royal 300 and Royal 350 were sold for control of *Ditylenchus myceliophagous* on mushrooms and *Meloidogyne* spp. on vegetables which being at a very high cost, have not been widely used. More recently, the facultative parasite, *P.lilacinus* has been produced in the Philippines as Bicon which can be applied for the control of several nematode species including root-knot nematodes. The American firm Mosanto is going to launch two commercial products one each of *P.lilacinus* and *V. chlamydosporium* respectively in the near future. *Trichoderma viride* has also been mass cultured and tried in farmer's (mainly in nursery) in India. Attempts for commercialisation of *T.viride* and *P.lilacinus* and other potential fungi are in progress.

Future Prospects

1. Intelligent manipulation of integrating ecofriendly methods like organic amendments, fungal bioagents and botanical antagonists to root-knot nematodes would prove very promising for the management package. Further as most of the fungal bioagents like *Aspergillus niger, Trichoderma viride* etc. has already been proved to be effective against many serious fungal diseases of agricultural crops, their use against nematode diseases would prove more profitable to our farmers.

2. Since many of the biopesticide *viz.*, *T. viride, A. niger* has already been commercialised both in India and abroad it is advisable to search for an isolate which would prove effective against both important fungal diseases as well root-knot nematode diseases in under field conditions. This, in addition to management of several fungal diseases in the field would check disease complexes arising from the same crop where nematode is known to predispose the fungal attack. The potential fungal and bacterial bioagents would also be combined with reduced dose of nematicides or organic amendment as a part of integrated approach for the management of plant-parasitic nematodes.
3. Biocontrol agents, botanicals and reduced doses of chemicals could be the major components of IPM programme.

References

Abu-Laban, A.Z., Saleh, A.H. (1992). Evolution of animal manures for mass production, storage and application of some nematode egg parasitic fungi. *Nematologica*, **38**: 237-244.

Amoncho, A. and Sasser, J.N. (1995) Biological control of *Meloidogyne incognita* with *Paecilomyces lilacinus*. *Biocontrol.* **4**: 51-61.

Arai, M., Mikami, Y., Fukushima, K., Utsumi, T and Yazawa, K. (1973). A new antibiotic, leucinostain, derived from *Penicillium lilacinum*. *J. Antibiot.* **26**: 157-161.

Bansal, R.K., Walia, R.K and Bhatti, D.S. (1998). Evaluation of some agro-industrial wastes for mass production of nematode parasitic fungus, *Paecilomyces lilacinus*. *Nematol. Medit.* **16**: 135-136.

Bansal, R.K., Walia, R.K. and Bhatti, D.S. (1992). Wood charcoal powder, a carrier of *Paecilomyces lilacinus* spores. *Nematol. Medit.* **20**: 5-7.

Bhatti, D.S. and Jain, R.K. (1997). Estimation of loss in okra, tomato and brinjal yield infested with *Meloidogyne incognita*. *Indian J. Nematol.* **1**: 37-41.

Bhagwati, B., B.K. Goswami and C.S. Singh (2000) Management of disease complex caused by root-knot nematode and wilt fungus through bioagents. *Indian J. Nematol.* (In press).

Cabanillas, E. and Barker, K.R. (1989) Impact of *Paecilomyces lilacinus* inoculum level and application time on control of *Meloidogyne incognita* on tomato. *J. Nematol.* **21**: 115-120.

Cabanillas, E., Barker, K.R. and Nelson, L.A. (1989b) Growth of isolates of *Paecilomyces lilacinus* and their efficacy in biocontrol of *Meloidogyne incognita* on tomato. *J. Nematol.* **21**: 164-172.

Candanedo, E., Lara, J., Jatala, P and Gonzales, F. (1983). Control biologico del nematodo *Meloidogyne incognita* con el hongo *Paecilomyces lilacinus.* Abstr. XXIII Meeting, APS Caribbean Division.

Carneiro. R.M.D.G. and Gomes, C.B. (1993) Methodology and pathogenicity tests effect of *Paecilomyces lilacinus* and *P. fumosoroseus* isolates to eggs of *Meloidogyne javanica. Nematologia Brasileira.* **17**: 66-75.

Caroppo, S., Perito, B and Pelagatti, O. (1990) *In vitro* evaluation of nematicide activity by several fungi against *Meloidogyne incognita* eggs. *Redia.* **73**: 451-462.

Cayrol, J.C., Djian, C and Pijarowski, L. (1989) Study of the nematicidal properties of the culture filtrate of the nematophagous fungus, *Paecilomyces lilacinus. Revue Nematol.* **12**: 331-336.

Chawla, G and Goswami. B.K. (1998) *In vitro* evaluation of culture filtrate of soil fungi on hatching of egg and mortality of *Meloidogyne incognita* and their in-vivo effect on root-knot nematode infecting mungbean. Proceedings of the " National symposium on rational approaches in nematode management for sustainable agriculture." November, 23-25, 1998. B.A. College of Agriculture, Anand Campus, Anand, India. pp. 17.

Chen-Sen Yu, Dickson, D.W., Mitchell, D.J and Chen, S.Y. (1996) Pathogenicity of fungi to eggs of *Heterodera glycines. J. Nematol.* **28**: 148-158.

Davide, R.G. and Batino, E. (1985) Biological control of root-knot nematodes on cotton through the use of fungi *Paecilomyces lilacinus* (Thom) Samson and *Gliocladium roseum* Bainler as seed treatment. *Phil. Agric.* **68**: 159-167.

Davide, R.G. and Zorilla, R.A. (1985) Evaluation of a fungus *Paecilomyces lilacinus* for the biological control of root-knot nematodes *Meloidogyne incognita* on okra as compared with nematicide isazofos. *Phil. Agric.* **68**: 493-500.

Davide, R.G. and Zorilla, R.A. (1986) Evaluation of a fungus *Paecilomyces lilacinus* for the biological control of root-knot nematodes *Meloidogyne incognita* on okra compared with a nematicide isazofos. Int. Nematol. *Network Newsl.* **3**: 32-33.

Davide, R.G. and Zorilla, R.A. (1995a) Evaluation of *Paecilomyces lilacinus* and some nematicides for the control of potato cyst nematode, *Globodera rostochiesis. Biocontrol* 1 (3): 69-76.

Darker, K.S., Mhase, M.L. and Shelke, S.S. (1990) Effect of placement of non-edible oilseed cakes for the control of root-knot nematodes on tomato. Internat. *Nematol. Net. Newsl.* 7: 5-7.

Desai, M. V., Shab, H, M and Pillai, S. N (1972) Effect of *Aspergillus niger* on root-knot nematode, *Meloidogyne incognita. Indian J. Nematol.* **2**: 210-214.

Devi, T.P and B.K. Goswami (1992) Effect of VA-mycorhiza on the disease incidence due to *Macrophomina phaseolina* and *Meloidogyne incognita* on cowpea. *Annals of Agric. Res.* **13**: 253-265.

Djian, C., Pijarowski, L., Ponchet, M., Arpin, N. and Favre-Bonvin, J. (1991) Acetic acid: a selective nematicidal metabolite from culture filtrates of *Paecilomyces lilacinus* (Thom) Samson and *Trichoderma longibrachiatum* Rifai. *Nematologica* **37**: 101-112.

Dube, B. and Smart Jr., G.C. (1987) Biological control of *Meloidogyne incognita* by *Paecilomyces lilacinus* and *Pasteuria penetrans. J. Nematol.* **19**: 222-227.

Eguiguren-Carrion, R. (1995) Control of *Meloidogyne incognita* and *Nacobbus* sp. with *Paecilomyces lilacinus* in the greenhouse and effect of nematicides on the fungus. *Biocontrol.* **4**: 41-49.

Endreeva, N.A., Ushakova, V.I. and Egorov, N.S. (1972) Study of proteolytic enzmes of different strains of *Penicillium lilacinum* (Thom) in connection with their fibrinolytic activity. *Microbiologiya* **41**: 364-368.

Fioretto, A.M.C. and Villacorta, A. (1989) Thermal requirements for the development of the nematogenic fungi *Paecilomyces lilacinus. Pesquisa Agropecria Brasileira* **24**: 975-978.

Fitter, P.F.L., Belder, E-den and Den, Belder, E. (1993) A time-lapse technique to study the effect of fungal products on embryogenesis of nematode eggs. Mededelingen Van de Faculteii *Landbouww-etenschappen, Universiteit-Gent.* **58**: 751-756.

Franco, J., Jatala, P. and Bocangel, M. (1981) Efficency of *Paecilomyces lilacinus* as a biocontrol agent of *Globodera pallida. Journal of Nematol.* **13** (4): 338-339.

Galper, S., Cohn, E., Spiegel, Y. and Chat, I. (1991) A collagenolytic fungus, *Cumminghamella elegans* for biological control of plant-parasitic nematodes. *Journal of Nematol.* **23**: 269-274.

Gintis, B.O., Morgan-Jones, G. and Rodriguez-Kabana, R. (1983) Fungi associated with several developmental stages of *Heterodera glycines* from an Alabama soybean field soil. *Nematropica* **13**: 201-213.

Goswami, B.K and Rumpenhorst, H.J. (1978) Association of an unknown fungus with potato cyst nematode, *Globodera rostochiensis* and *G. pallida. Nematologica*, **24**: 251-256.

Goswami, B.K. and Vijayalakshmi (1981) Effect of some indigenous plant materials and oil-cakes amended soil on the growth of tomato and root-knot nematode populations. *Indian J. Nematol.* **11**: 121.

Goswami, B.K., Haque, M.M., Mishra, S.D. and Mojumdar, V. (1989) Comparative efficacy of Hind-o-meal, Karanj and castor oilseed cakes with a nematicide, carbofuran against root-knot nematode, *Meloidogyne incognita* in cowpea. *Annals of Agric. Res.* **10**: 316-318.

Goswami, B.K. and Sharma, S.B. (1999) Management of root-knot disease of tomato with integration of fungal bioagents (*Aspergillus terreus* and *Paecilomyces lilacinus)* Abstract. Nat. Symp. On Pl. Dis. Scenario under changing agroecosystems. Oct. 29-30, 1999. HPKV, Palampur, HP., 42pp.

Goswami, B.K. and Archana Mittal (2000) Effect of *Aspergillus fumigatus* and *Fusarium solani* alone and in combination along with neem oilseed cake against *Meloidogyne incognita* infecting tomato. *Annals of Agric. Res.* (In press)

Gaonkar, S.B.N and Sreenivasan, M.N. (1994) Effect of inoculation with *Glomus fasciculatum* in conjunction with different organic amendments on growth and yield of wheat. *Microbiol. Res.* **4**: 419-423.

Isogai, A., Suzuki, A., Higashikawa, S., Kuyama, S. and Tamura, S. (1980a) Constituents of a peptidal antibiotic, p. 168, produced by *Paecilomyces lilacinus* (Thom) Samson, *Agr. Biol. Chem.* **44**: 3029-3031.

Isogai, A., Suzuki, A., Higashikawa, S. and Tamura, S. (1980b) Structure of peptidal antibiotic P 168 produced by *Paecilomyces lilacinus. Agr. Biol. Chem.* **44**: 3033-3036.

Isogai, A., Suzuki, A., Higashikawa, S. Kuyama, S. and Tamura, S. (1981) Isolation and biological activity of a peptidal antibiotic, p. 168. *Agr, Biol. Chem.* **45**: 1023-1024.

Jatala, P. (1981) Jatala, P. (1981) Biological control of *Meloidogyne* species: Methodology for preparation and establishment of *Paecilomyces lilacinus* for field inoculation. Int. *Meloidogyne* Proj. Proc. 3rd Res. Plann. Conf. on Root-knot nematodes, *Meloidogyne* spp. Jakarata Region VI, 228-231.

Jatala, P (1983) Potential and prospects of biological control of nematodes. Abstr. XXIII meeting APS Caribbean Division.

Jatala, P. (1985) "Biological control of nematodes." In: *An Advanced Treatise on Meloidogyne.* Vol. I. Biology and Control. (Eds. Sasser, J.N. and Carter, C.C.) N.C.S. University Graphics, Raleigh, 303-308.

Jatala, P. (1986) Biological control of plant parasitic nematodes. *Ann. Rev. Phytopathol.* **24**: 453-489.

Jatala, P., Kaltenbach, R. and Bocangel, M. (1979). Biological control of *Meloidogyne incognita acrita* and *Globodera pallida* on potatoes. *J. Nematol.* **11**: 303.

Jonathan, E.I., Padmanabham, D. and Ayyamperumal, A. (1995) Biological control of root-knot nematode on betelvine, Piper betle by *Paecilomyces lilacinus. Nematol. Medit.* **23**: 191-193.

Kerry, B.R. (1980) Biocontrol: fungal parasites of female cyst nematodes. *J. Nematol* **12**: 253-259.

Kerry, B.R. and Crump, D.H. (1977) Observations on fungal parasites of females and eggs of the cereal cyst nematodes, *Heterodera avenae* and other cyst nematodes. *Nematologica.* **23**: 193-201.

Khan, M.W., Asharf, S.S. and Haider, S.R. (1988) An analysis of biocontrol efficacy of *Paecilomyces lilacinus* in management of root-knot nematodes. Int. Conf. Res. Plant Sciences and its Relevance to the Future. Delhi, India, 67.

Khan, M.W. and Esfahani, M.N. (1990) Efficacy of *Paecilomyces lilacinus* for controlling *Meloidogyne incognita* on tomato in greenhouse in India. Pakistan *J. Nematol.* **8**: 95-100.

Khan, S.T. and Khan, T.A. (1992) Effect of culture filtrates of soil fungi on the hatching and mortality of root-knot nematode, *Meloidogyne incognita*. *Curr. Nematol.* **3**: 53-60.

Khan, M.W. (1990) "Biocontrol of plant-parasitic nematodes in closer perspectives." In: *Progress in Plant Nematology* (Eds, S.K. Saxena *et al.*).

Khan, M.W. and Hussain, S.I. (1986). Parasitism of *Meloidogyne incognita* by *Fusarium solani*. Intern. *Nematol. Netw. Newsl.* **3** (2): 11-13.

Kuhn, J. (1877) Vorlaufiger Bericht uber die bisherigen ergebnisse der selt Jahre 1875 in auftrage des Vereins fur rubezucker Industrie Z. ver. Rubenzucker Indus. Disch. Reiches. 452-457.

Leiz, De. F.A.A.M. and Kerry, B.R. (1991) The nematophagous fungus, *Verticillum chlamydosporum* as a potential biocontrol agent for *Meloidogyne arenaria*. *Revue de Nematologie*, **14** (1): 157-164.

Leiz, De. F.A.A.M., Kerry, B.R. and Deunchy, J.A. (1992) The effect of fungal application rate and nematode density on the effectiveness of *Verticillum chlamydosporum* as the biocontrol agent for *Meloidogyne incognita*. *Nematologica*, **38** (1): 112-122.

Liu, X.Z., Liu, W.M. and Zhang, D.S. (1995) Biological characteristics of *Paecilomyces lilacinus* associated with soybean cyst nematode. *Chinese J. Biological Control*. **11**: 70-74.

Lodhe, G. (1874) *Einge heven parasitishehen pilze*. Tageblatt der 47 Versamunhung deutscher haturforseher und Aerzste Berslan, 203-206.

Maheshwari, T.U. and Mani, A. (1988) Combined efficacy of *Pasteuria penetrans* and *Paecilomyces lilacinus* on the biocontrol of *Meloidogyne javanica* on tomato. Int. *Nematol. Network Newl.* **5**: 10-11.

Mani, A. and Anandam, R.J. (1989) Evaluation of plant leaves, oilcakes and agro-industrial wastes as substrates for mass multiplication of nematophagous fungus, *Paecilomyces lilacinus*. *J. Biological Control* **3**: 56-58.

Mani, A., Murthy, I.R., Rao, P.K. and Prasad, V.D. (1989) Growth of *Paecilomyces lilacinus* on natural substrates and its efficacy against citrus nematode, *Tylenchulus semipentrans*. *J. Biological Control*. **3**: 59-61.

Mankau, R. (1968) Reduction of root-knot disease with organic amendments under semifield conditions. *Plant Dis. Reptr.* **52**: 313-319.

Meshram, N.J. and Goswami, B.K. (1989) Role of dominant rhizosphere fungi isolated from soil amended with mustard and karanj cakes on hatching and mortality of *Meloidogyne incognita* juveniles. *Indian J. Nematol.* **19**: 180-185.

Oduor, O.P., Sikora, R.A., Waudo, S.W. and Schuster, R.P. (1996) Effects of aldicarb and mixed cropping with *Datura stramonium, Ricinus communis* and *Tagetes minuta* on the control and integrated management of *Meloidogyne javanica*. *Nematologia* **42**: 127-130.

Oduor, O.P. and Waudo, S.W. (1995) Effects of fungi on hatching and parasitism of eggs, juveniles and females of root-knot nematode. *Pakistan. J. Nematol* **13**: 119-127.

Okafor, N. (1967) Decomposition of chitin by microorganisms isolated from a temperate and tropical soil. *Nova Hedwigia* **13**: 209-226.

Patel, R.R., Patel, D.J. and Patel, B.A. (1991) Influence of organic amendments on growth and sporulation of nematophagous fungus, *Paecilomyces lilacinus* (Thom) Samson. *Curr. Nematol.* **2**: 39-40.

Patel, D.J., Vyas, R.V., Patel, B.A. and Patel, R.S. (1995) Bioefficacy of *Paecilomyces lilacinus* in controlling *Meloidogyne javanica* (Pathotype 2) on groundnut. *Int. Archais Newsl.* **15**: 46-47.

Rao, M.S. and Reddy, P.P. (1994) A method for conveying *Paecilomyces lilacinus* to soil for management of root-knot nematodes on egg plant. *Nematol. Medit.* **22**: 265-267.

Rao, U. and Goswami, B.K. (1996) Comparative efficacy of soil amendments with carbofuran against root-knot nematode, *Meloidogyne incognita* on cowpea. *Pest. Res. J.* **8** (1): 87-89.

Rao, M.S., Reddy, P.P. and Das, S.M. (1996) Effect of irrigation of *Calotropis procera* leaf and *Glomus fasciculatum* on the management of *Meloidogyne incognita* infesting tomato. *Nematol. Medit.* **74** (1): 59-61.

Shahzad, S. and Ghaffar, A. (1987) Field application of *Paecilomyces lilacinus* and furadan for the control of root-knot disease of okra and mung. *Int. Nematol. Ntework Newsl.* **4**: 33-34.

Sharma, A. and Trivedi, P.C. (1987) Screening substrates suitable for the growth of *Paecilomyces lilacinus. Int. Netmatol. Network Newsl.* **4**: 24-26.

Sharma, M. and Saxena, S.K. (1992) Effect of culture filtrates of *Rhizoctonia solani* and *Trichoderma viride* on hatching of larvae of root-knot nematode, *Meloidogyne incognita. Curr. Nematol.* **3**: 61-64.

Siddiqui, Z.A. and Hussain, S.I. (1991) Control of *Meloidogyne incognita* and *Macrophomina phaseolina* on chickpea by fungal filtrates. *Pakistan J. Nematol.* **9**: 131-137.

Siddiqui, Z.A. and Mahmood, I. (1995) Management of *Meloidogyne incognita* race 3 and *Macrophomina phaseolina* by fungus culture filtrates and *Bacillus subtilis* on chickpea. *Fundm. Appl, Nematol.*, **18**: 71-76.

Singh, R.S. and Sitaramaiah, K. (1996) incidence of root-knot of okra and nematodes on oil-cake amended soil. *Plant. Dis. Reptr.* **50**: 668-672.

Singh, S.P., Veena, P., Khan, A.M. and Saxena, S.K. (1983) Inhibitory effect of culture filtrates of some rhizosphere fungi of tomato as influenced by oil-cakes on the mortality and larval hatch of *Meloidogyne incognita. Nematologia Medit.* **11** (2): 119-123.

Sosamma, V.K., Geetha, S.M. and Koshy, P.K. (1994) Effect of the fungus, *Paecilomyces lilacinus* on the burrowing nematode, *Radopholus similis* infesting betelvine. *Indian J. Nematol.* **24**: 50-53.

Tabreiz, A., Khan, T.A., Hussain, S.I. and Azam, M.F. (1884) Effect of culture filtrates of eight species of *Aspergillus* on the hatching and mortality of *Meloidogyne incognita. Indian J. Nematol.* **14**: 50-74.

Upadhaya, K.D. and Dwivedi, K. (1988) Role of fungi in biological control of plant-parasitic nematodes. *Brit Crop. Prod. Conn.*, **3**: 1205-1208.

Vicente, N.E. and Acosta, N. (1992) Biological and chemical control of nematodes in *Capsicum annuum*. *J. Agric. Univ. Puerto Rico* **76**: 171-176.

Vicente, N.E., Acosta, N. and Sanchez, L.A. (1989) Rice (*Oryza sativa L.*) substrates and growth of the fungus *Paecilomyces lilacinus,* a nematode control agent. *J. Agric. Univ. Puerto Rico* **73**: 79-82.

Vicente, N.E., Sanchez, L.A. and Acosta, N. (1991) Effect of granular nematicides and the fungus *Paecilomyces lilacinus* in nematode control in watermelon. *J. Agric. Univ. Puerto Rico* **75**: 307-309.

Villaneva, L.M. and Davide, R.G. (1984) Influence of pH, temperature, light and agar media on the growth and sporulation of a nematophagous fungus, *Paecilomyces lilacinus* (Thom) *Samson. Phil. Agric.* **67**: 223-231.

Walia, R.K. and Bansal, R.K. (1992) Factors governing efficacy of nematode oviparasitic fungus, *Paecilomyces lilacinus:* effects of fungus inoculum level. *Afro-Asian Nematol. Network* **1**: 9-11.

Walia, R.K., Bansal. R.K. and Bhatti, D.S. (1991) Effect of *Paecilomyces lilacinus* application time and method in controlling *Meloidogyne javanica* on okra. *Nematol. Medit.* **19**: 247-249.

Wyss, U., Vossand, B. and Janson, H.B. (1992) In-vitro observation on the infection of *Meloidogyne incognita* eggs by the zoospore fungus, *Catenaria anguillulae*. *Fundm. Appl. Nematol.* **15** (2): 113-139.

Zaki, F.A. (1994a) Effect of culture filtrates of *Paecilomyces lilacinus* on *Meloidogyne javanica*. *Nematol. Medit.* **22**: 41-43.

Zaki, F.A. (1994b) Dose optimisation of *Paecilomyces lilacinus* for the control of *Meloidogyne javanica* on tomato. *Nematol. Medit.* **22**: 45-47.

Zaki, F.A. and Bhatti, D.S. (1988) Economical method for mass culturing of *Paecilomyces lilacinus* (Thom) *Samson. Curr. Sci.* **57**: 135.

Zaki, F.A. and Bhatti, D.S. (1991) Effect of culture media on sporulation *of Paecilomyces lilacinus* and its efficacy against *Meloidogyne javanica* in tomato. *Nematol. Medit.* **19**: 211-212.

Zaki, M.J. and Maqbool, M.A. (1991) *Paecilomyces lilacinus* controls *Meloidogyne javanica* on chickpea. *Int. Chickpea Newsl.* **25**: 22-23.

Zuckerman, B.M., Matheny, M. and Acosta, N. (1994) Control of plant-parasitic nematodes by a nematicidal strain of *Aspergillus niger*. *J. Chem. Ecol.* **20**: 33-43.

❑❑❑

14

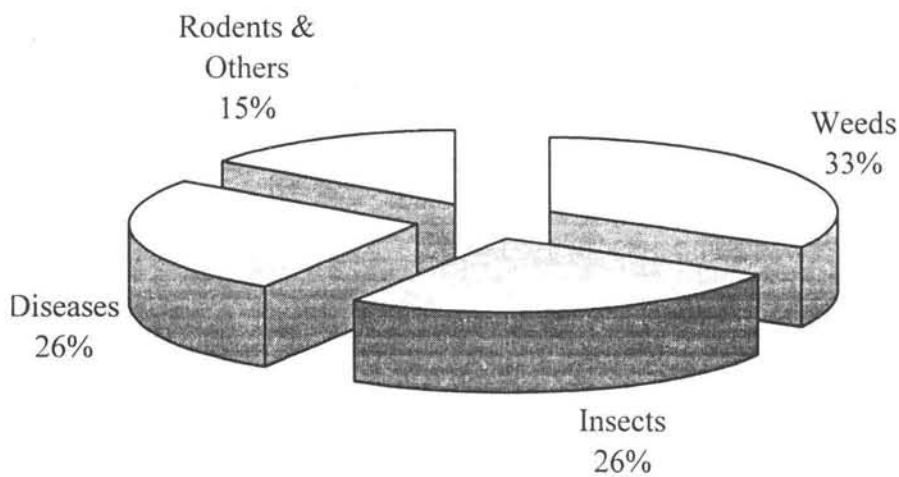
Bio-intensive Integrated Pest Management Modules for Nematode Management

Dr. D. Prasad

Introduction

Crop pests continue to cause losses of about 18 per cent of the crop yields worth more than Rs. 60,000 crore annually (Fig. 1), despite the fact that more than 48,000 metric tons of technical grade chemical pesticides are used to manage the pests in the country (Fig. 2). Insecticides constitute almost 60 per cent of the total pesticides used, followed by fungicides and herbicides (Fig. 3). Indiscriminate and injudicious use of chemical pesticide is associated with a number of adverse effects on health and environment.

Fig. 1: Share of losses caused by different pests



Source: *Validated IPM Technologies for Selected Crops* (2004), NCIPM, New Delhi

Blocks on the Pesticide Treadmill

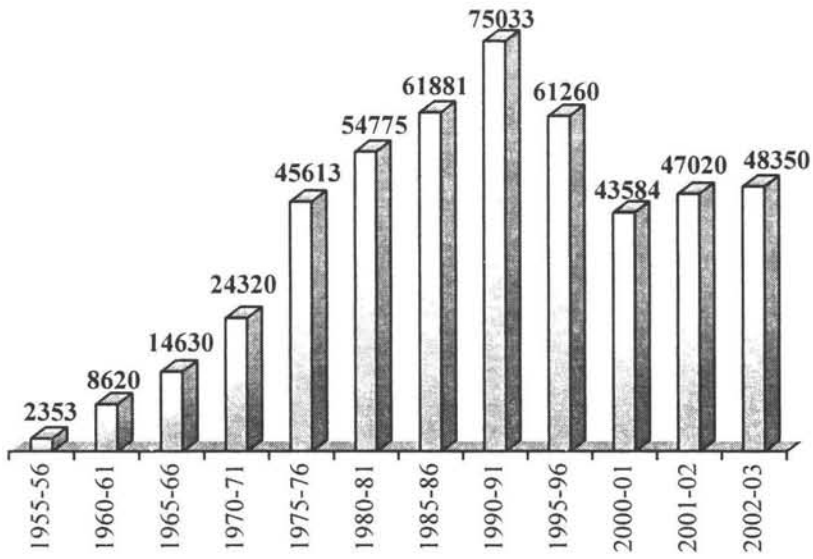
Resistance: Pesticide use exerts a powerful selection pressure for changing the genetic make-up of a pest population. Naturally resistant individuals in a pest population are able to survive pesticide treatments. The survivors pass on the resistance trait to their offspring. The result is a much higher percentage of the pest population resistant to a pesticide.

Resurgence: Pesticides often kill off natural enemies along with the pest. With their natural enemies eliminated, there is little to prevent recovered pest populations from exploding to higher, more damaging numbers than existed before pesticides were applied. Additional chemical pesticide treatments only repeat this cycle.

Secondary Pests: Some potential pests that are normally kept under good control by natural enemies become actual pests after their natural enemies are destroyed by pesticides. Mite outbreaks after pesticide applications are a classic example.

Residues: Only a minute portion of any pesticide application contacts the target organism. The remainder may degrade harmlessly, but too often water, wind, and soil will carry pesticides to non-target areas and organisms, affecting the health of human and wildlife populations.

Fig. 2: Trend of pesticide consumption in India



Source: *Validated IPM Technologies for Selected Crops* (2004), NCIPM, New Delhi

Classification of Active Pesticide (Nematicide) Ingredients (based on their hazard level) by WHO

Extremely hazardous [Ia (LD50 = less than 1 mg/kg body weight)]

Aldicarb (Temik) 10G systemic (use banned w.e.f. 17/7/2003)

Phorate (Thimet) 10G systemic

Highly hazardous [Ib (LD50 = less than 1-50 mg/kg body weight)]

Carbofuran (Furadan) 3G systemic

Moderately hazardous [(LD50 = 50-500 mg/kg body weight)]

Carbosulfan (Marshal) 25 EC systemic (Contact & Stomach)

Integrated Pest Management

Pest management is an ecological matter. The size of a pest population and the damage it inflicts is, to a great extent, a reflection of the design and management of a particular agricultural ecosystem. FAO in 1967 defined as "The IPM is a pest management system is that, in the context of associated environment and population dynamics of the pest species, utilises all suitable techniques and methods in as compatible a manner as possible and maintains pest populations at levels below those causing economic injury." Government of India, in the National Agricultural Policy, has laid emphasis on integrated pest management (IPM) and use of biotic agents to minimise the indiscriminate and injudicious use of chemical pesticides in agriculture. The IPM follows a system approach while combining a wide array of crop production and protection practices to reduce the economic losses caused by the pests. IPM emphasises on careful monitoring of pests and conservation of their natural enemies. Decisions to intervene by use of plant protection tactics including chemicals are based on monitoring.

Framework of IPM Strategy

Integrated Pest Management is a holistic guiding principle that encompasses all the activities from selection of crop to the harvest and storage. Broadly speaking, however, IPM strategies are based on three main pillars:

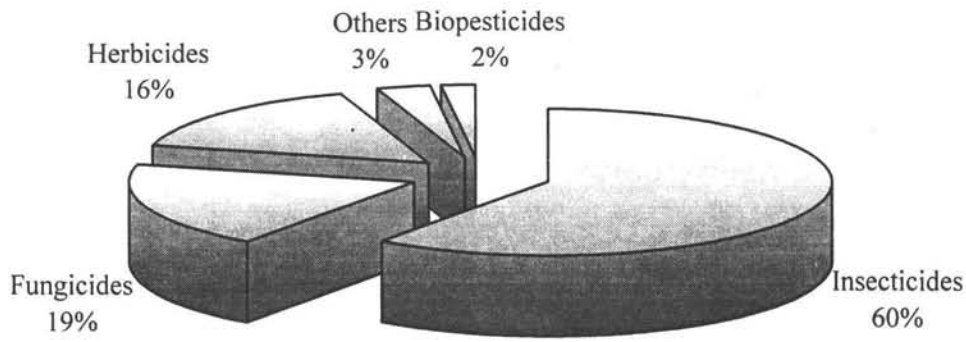
(i) Prevention
(ii) Monitoring
(iii) Intervention

Most of the IPM activities emphasise heavily on the preventive measures especially before the crop is sown, *i.e.*, at the field preparation or seed treatment stages

since the initial inoculum of the propagules is largely responsible for the subsequent high pest build up. Agronomic practices such as deep summer ploughing, soil solarisation, cleansing of crop refuse, elimination of weed hosts, crop rotation, water management, intercropping/mixed cropping, trap crop, border cropping, nutrition management, etc. and genetic sources of resistance along with habitat management are the major tools of the prevention.

Regular monitoring is very crucial to pest management as it is one of the most important decision-making tools. An efficient monitoring programme can pay big dividends in lowering pest control costs. An Agro-Eco System Analysis (AESA) based on crop health at different stages of growth, population dynamics of pests and natural enemies, soil condition, climatic factors and farmers' past experiences are considered for decision-making. Field scouting, use of sticky traps, pheromone traps and soil sample analysis for soil-borne plant pathogens are usually employed as monitoring tools. Diagnostic techniques, economic threshold level (ETL) and pest forecasting modes are now available to assist in proper timing of IPM interventions.

Fig. 3: Share of different classes of pesticides being used in India



Source: *Validated IPM Technologies for Selected Crops* (2004), NCIPM, New Delhi

Various IPM interventions are devised to reduce the effects of economically damaging pest populations to acceptable levels. Mechanical, biological, cultural and chemical control measures are applied individually or in combination. Some of the principal IPM interventions include, cultural and physical measures, monitoring of pests, biocontrol agents (biopesticides, natural enemies), host plant resistance, botanicals and target-specific, less hazardous chemical pesticides.

Biointensive IPM (BIPM)

Frisbie and Smith proposed Biointensive IPM for the first time in 1991 as "a system's approach to pest management based on an understanding of pest ecology. It begins with steps to accurately diagnose the nature and source of pest problems, and then relies on a range of preventive tactics and biological controls to keep pest populations within acceptable limits. Reduced-risk pesticides are used if other tactics have not been adequately effective, as a last resort, and with care to minimise risks."

Why Move to Biointensive IPM?

Biointensive IPM incorporates ecological and economic factors into agricultural system design and decision-making, and addresses public concerns about environmental quality and food safety. The benefits of implementing biointensive IPM can include reduced chemical input costs, reduced on-farm and off-farm environmental impacts, and more effective and sustainable pest management. An ecology-based IPM has the potential of decreasing inputs of fuel, machinery, and synthetic chemicals—all of which are energy intensive and increasingly costly in terms of financial and environmental impact. Such reductions wll benefit the grower and society.

Over-reliance on the use of synthetic pesticides in crop protection programmes around the world has resulted in disturbances to the environment, pest resurgence, pest resistance to pesticides, and lethal and sub-lethal effects on non-target organisms, including humans. These side effects have raised public concern about the routine use and safety of pesticides. The primary goal of biointensive IPM is to provide guidelines and options for the effective management of pests and beneficial organisms in an ecological context. The flexibility and environmental compatibility of a biointensive IPM strategy make it useful in all types of cropping systems.

Even conventional IPM strategies help to prevent pest problems from developing, and reduce or eliminate the use of chemicals in managing problems that do arise. Biointensive IPM would likely decrease chemical use and costs even further.

"Conventional" Vs "Biotensive" IPM

The following are the concepts that are common to both conventional and biointensive IPM:

* The first step in sustainable and effective pest management is looking at the design of the agricultural ecosystem and considering what ecological concepts can be applied to the design and management of the system to better manage pests and their parasites and predators.

* An understanding that the presence of a pest does not necessarily constitute a problem. Before a potentially disruptive control method is employed, appropriate decision-making criteria are used to determine whether or not pest management actions are needed.
* A consideration of all possible pest management options before action is taken.
* A philosophy that IPM strategies integrate a combination of all suitable techniques in as compatible a manner as possible; it is important that one technique not conflict with another.

However, conventional IPM differs from Bio-intensive IPM in a sense that the emphasis of the later is on proactive measures to redesign the agricultural ecosystem to the disadvantage of a pest and to the advantage of its parasite and predator complex.

The Pest Manage/Ecosystem Doctor

The pest manage is the most important link in a successful IPM programme. The manager must know the biology of the pest and the beneficial organisms associated with the pest, and understand their interactions within the farm environment. As a detailed knowledge of the pest is developed, weak links in its life cycle become apparent. These weak links are phases of the life cycle when the pest is most susceptible to control measures. The manager must integrate this knowledge with tools and techniques of Bio-intensive IPM to manage not one, but several pests. He or she must pay close attention to the pulse of the managed ecosystem and stay abreast of development in IPM and crop/pest biology and ecology. In this way, the ecosystem manager can take a proactive approach to managing pests, developing ideas about system manipulations, testing them, and observing the results.

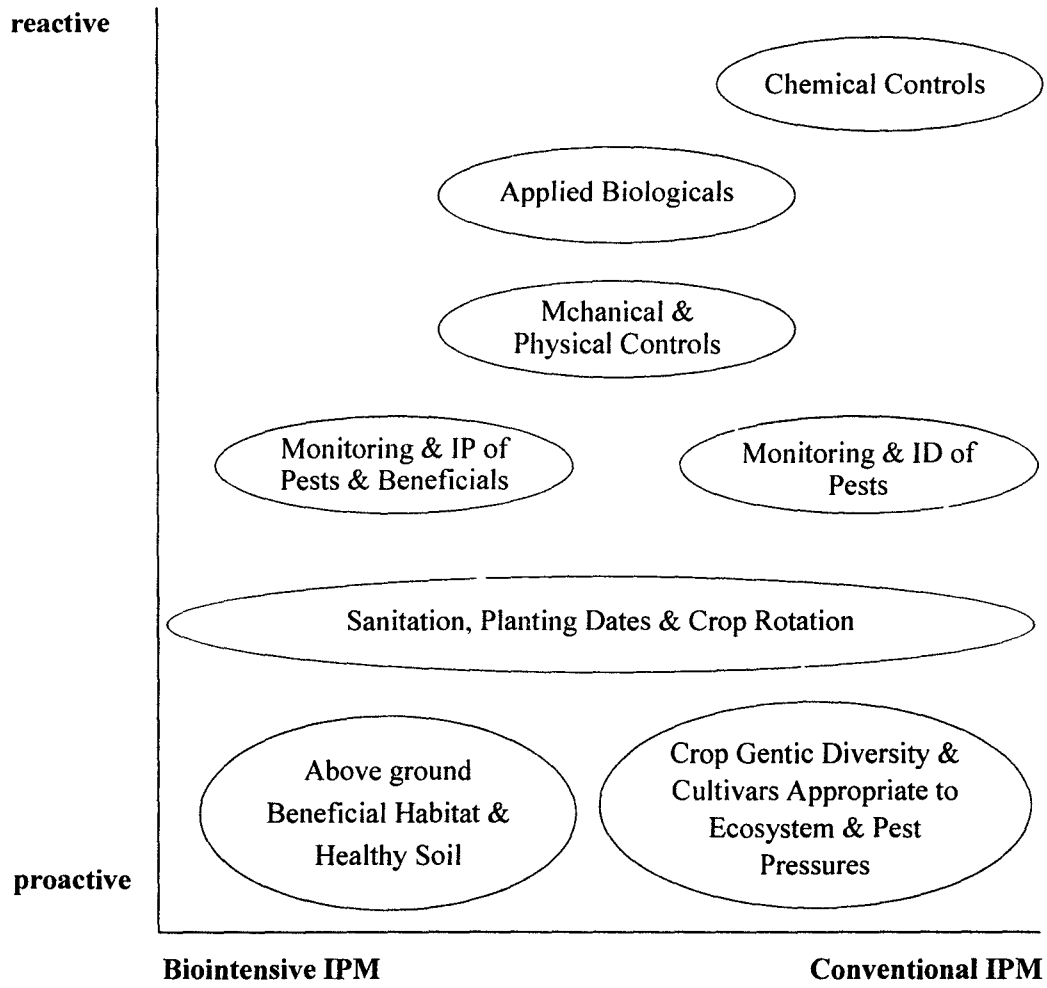
Implementation of BIPM

Pest Identification

A crucial step in any IPM programme is to identify the pest. The effectiveness of both proactive and reactive pest management measures depend on correct identification. Misidentification of the pest may be worse than useless; it may actually be harmful and cost time and money. After a pest is identified, appropriate and effective management depends on knowing answers to a number of questions. These may include:

* What plants are hosts and non-hosts of this pest?
* When does the pest emerge or first appear?

* Where does it lay its eggs? In the case of weeds, where is the seed source? For plant pathogens, where is the source(s) of inoculum?
* Where, how, and in what form does the pest overwinter?
* How might the cropping system be altered to make life more difficult for the pest and easier for its natural controls?



Monitoring

Monitoring involves systematically checking crop fields for pests and beneficials, at regular intervals and at critical times, to gather information about the crop, pests, and natural enemies. Sweep nets, sticky traps, and pheromone traps can be used to collect insects for both identification and population density information. Leaf counts are one

method for recording plant growth stages. Square-foot or larger grids laid out in a field can provide a basis for comparative weed counts. Records of rainfall and temperature are sometimes used to predict the likelihood of disease infections.

Economic Injury and Action Levels

The economic *injury* level (EIL) is the pest population that inflicts crop damage greater than the cost of control measures. Because growers will generally want to act before a population reaches EIL, IPM programmes use the concept of an economic *threshold* level (ETL or ET), also known as an action threshold. The ETL is closely related to the EIL, and is the point at which suppression tactics should be applied in order to prevent pest populations from increasing to injurious levels.

Components of Biointensive IPM

IPM options may be considered proactive or reactive. Proactive options, such as crop rotations and creation of habitat for beneficial organisms, permanently lower the carrying capacity of the farm for the pest. The carrying capacity is determined by factors like food, shelter, natural enemies' complex, and weather, which affect the reproduction and survival of a species. Cultural controls are generally considered to be proactive strategies.

The second set of options is more reactive. This simply means that the grower responds to a situation, such as an economically damaging population of pests, with some type of short-term suppressive action. Reactive methods generally include inundative releases of biological controls, mechanical and physical controls, and chemical controls.

Proactive Strategies (Cultural Control)

Cultural controls are manipulations of the agroecosystem that make the cropping system less friendly to the establishment and proliferation of pest populations. Although they are designed to have positive effects on farm ecology and pest management, negative impacts may also result, due to variations in weather or changes in crop management.

Maintaining and increasing biological diversity of the farm system is a primary strategy of cultural control. Decreased biodiversity tends to result in agroecosystems that are unstable and prone to recurrent pest outbreaks and many other problems. Systems high in biodiversity tend to be more "dynamically stable"—that is, the variety of organisms provide more checks and balances on each other, which helps prevent one species (*i.e.*, pest species) from overwhelming the system.

There are many ways to manage and increase biodiversity on a farm, both above ground and in the soil. Diversity above ground influences diversity below ground. Research has shown that up to half of a plant's photosynthetic production (carbohydrates) is sent to the roots, and half of that (along with various amino acids and other plant products) leaks out the roots into the surrounding soil, providing a food source for microorganisms. These root exudates vary from plant species to plant species and this variation influences the type of organisms associated with the root exudates.

Factors influencing the health and biodiversity of soils include the amount of soil organic matter; soil pH; nutrient balance; moisture; and parent material of the soil. Healthy soils with a diverse community of organisms support plant health and nutrition better than soils deficient in organic matter and low in species diversity. Research has shown that excess nutrients (*e.g.*, too much nitrogen) as well as relative nutrient balance (*i.e.*, ratios of nutrients—for example, twice as much calcium as magnesium, compared to equal amounts of both) in soils affect insect pest response to plants. Imbalances in the soil can make a plant more attractive to insect pests, less able to recover from pest damage, or more susceptible to secondary infections by plant pathogens. Soils rich in organic matter tend to suppress plant pathogens. Overall, a healthy soil with a diversity of beneficial organisms and high organic matter content helps maintain pest populations below their economic thresholds.

Genetic diversity of a particular crop may be increased by planting more than one cultivar. Species diversity of the associated plant and animal community can be increased by allowing trees and other native plants to grow in fence rows or long water ways, and by integrating livestock into the farm system.

Crop rotations: The practice of growing several different crops on the same land in successive years or seasons. It radically alters the environment both above and below ground, usually to the disadvantage of pests of the previous crop. The same crop grown year after year on the same field will inevitably build up populations of organisms that feed on that plant, or, in the case of weeds, have a life cycle similar to that of the crop. For example, crop rotation for at least 2-3 years with non-solanaceous vegetables like cabbage, cauliflowers, etc. for Potato cyst nematode control.

Multiple cropping: It is the sequential production of more than one crop on the same land in one year. Depending on the type of cropping sequence used, multiple cropping can be useful as a weed control measure, particularly when the second crop is interplanted into the first.

Effect of different combinations of marigold (cv. Crackerjack) with brinjal (cv. BR-112) on growth characters and nematode populations *(M. javanica)* (Dhangar *et al.*, 2002)

Treatments	Root-knot Index (scale 1-5)	Yield (kg)	% increase in yield over control
Brinjal + Marigold (Alternate within row)	2.5	12.4	82.8
Brinjal + Marigold (Alternate rows)	2.8	10.6	55.9
Brinjal + Marigold (one brinjal row alternated with two marigold rows)	3.5	9.1	33.8
Brinjal alone (control)	4.8	6.8	
CD at 5%	0.8	1.5	

Cover crops: Crops planted not for harvest but to improve soil quality, prevent erosion, and control weeds and insects. Such crops are usually tilled into the soil to improve fertility for the next food crop to be planted there. For example, growing jute in the ufra infested field reduces rice stem nematode populations.

Intercropping: It is the practice of growing two or more crops in the same, alternate, or paired rows in the same area. The advantage of intercropping is that the increased diversity helps "disguise" crops from pests, and if done well, may allow for more efficient utilisation of limited soil and water resources. For example, growing French Marigold *(Tagetes patula)* between rows of main crop for management of Root lesion nematode *(Pratylenchus* spp.).

Resistant varieties: These are continually being bred by researchers. The plants from these seeds will have a good chance of being better suited to the local environment and of being more resistant to insects and diseases. Since natural systems are dynamic rather than static, breeding for resistance must be an ongoing process, especially in the case of plant disease, as the pathogens themselves continue to evolve and become resistant to control measures.

Disease-free seed and plants: Use of disease-free seed and nursery stock is important in preventing the introduction of disease.

Sanitation: It involves removing and destroying the overwintering or breeding sites of the pest as well as preventing a new pest from establishing on the farm (*e.g.*, not allowing off-farm soil from farm equipment to spread nematodes or plant pathogens to

your land). This strategy has been particularly useful in horticultural and tree-fruit crop situations involving twig and branch pests.

Host Plant Resistance (Ali, 1997)

Crop	Nematode	Resistant Cultivars
Brinjal	*Meloidogyne* spp.	Vijay, Black Beauty, Banaras Giant
Capsicum	*M. incognita*	NP 46A, G4, Mirch 1, Red Long CA(P)63
Tomato	*M. incognita, R. reniformis*	SL-120, Punjab NR-7, Hissar Lalit
Pea	*M. incognita, M. javanica*	T-44 DMR 7, KEP 130, HFD 4, KFPD 46
Lentil	*M. incognita, M. javanica*	DPL-14, PL81-D, PL81-340
Chickpea	*M. incognita, M. javanica*	BGM 481, BGM 483, G 288341, BG 369, BGM 481, GL 88341, GMS 815
Mungbean	*M. javanica*	GM 85-2, ML 323
Urdbean	*M. javanica*	TPU3, WBU 105
Pigeonpea	*M. incognita, M. javanica*	Pusa 23, GAUT 87-2 H82-1, 86-1, IPH 732, TH 9, UG 218
Cowpea	*R. reniformis*	Cowpea 1
Chilli	*R. reniformis*	Pusa jawala

Optimum growing conditions: These are always important. Plants that grow quickly and are healthy can compete with and resist pests better than slow-growing, weak plants.

Mulches: These living or non-living structures, are useful for suppression of weeds, insect pests, and some plant diseases. Mulching helps to minimise the spread of soil-borne plant pathogens by preventing their transmission through soil splash. Mulch, if heavy enough, prevents the germination of many annual weed seeds. Recent springtime field tests at the Agricultural Research Service in Florence, South Carolina, have indicated that red plastic mulch suppresses root-knot nematode damage in tomatoes by diverting resources away from the roots (and nematodes) and into foliage and fruit.

Preventing further Spread of Nematodes

* Using certified planting material.
* Using soilless growing media in greenhouses.
* Cleaning soil from equipment before moving between fields.
* Keeping excess irrigation water in a holding pond to settle nematodes and planning irrigation to minimise the amount of excess water.
* Preventing or reducing animal movement from infested to uninfested fields.
* Composting manure to kill any nematodes that might be present, before applying it to fields.
* Eliminating important weed hosts.

Soil Amendments

Many different types of amendments and composted materials have been applied to soil to suppress populations of plant parasitic nematode and improve crop yield and plant health. Animal manures, poultry litter, and disk-incorporated cover crop residues are typical examples of soil amendments used in agriculture to improve soil quality and as a means for enhancing biocontrol potential of soil. Some amendments which contain chitin and inorganic fertilizers that release ammoniacal nitrogen into soil suppress nematode populations directly and enhance the selective growth of microbial antagonists of nematodes. More recently, composted municipal wastes and sludges have been used to amend soil to improve soil fertility, organic matter content, water holding capacity, nutrient retention, and cation exchange capacity.

Suppression of soil-borne pathogens via the incorporation or simple mulching of composted amendments is reputedly based on enhanced microbial activity and increased numbers of antagonists generated by decomposition of the amendment in soil. Soils with a diversity of beneficial microorganisms are more suppressive to pathogens than soils with little or no biological diversity. Other possible mechanisms for pathogen suppression by composts include direct inhibition of the pathogen or reduced infectivity of the organisms into the plant host. Population increases of beneficial organisms in soil appears to be the direct result of environmental changes brought about by the amendments after addition to soil. This suggests that to sustain soil suppressiveness, amendments must be periodically reapplied to maintain the soil environment conductive to antagonists.

The level to which soil-borne pest and disease control can be achieved is not only related to the type of material but to the age of the compost. Nematode and disease

suppression has been repeatedly demonstrated with composted municipal yard wastes containing significant quantities of tree bark. If the compost is immature, the product may not only be difficult to handle and have an offensive odor, but may contain salts and metabolites toxic to plants. For example, weed suppression has been demonstrated with some types of immature composted materials which contain and/or produce organic acids with phytotoxic properties.

In summary, the high rates of application (tons/acre) and attendant costs required for crop response and nematode control for many different types of organic amendments, and the apparently rapid losses of the materials in soil appears to preclude use of these materials primarily to homeowner or small farm operations at this time. However, with additional research and advances in application technology and use efficiency, use of soil amendments may become an integral component of Florida crop production systems.

Mechanical and Physical Controls

Methods included in this category utilise some physical component of the environment, such as temperature, humidity, or light, to the detriment of the pest. Common examples are flaming, flooding, soil solarisation, and plastic mulches to kill weeds or to prevent nematode damage.

Soil Solarisation

Soil solarisation is a non-chemical technique in which transparent polyethylene tarps are laid over moist soil for a 6 to 12 week period to heat non-cropped soils to temperatures lethal to nematodes and other soil-borne pathogens. Soil temperatures are magnified due to the trapping of incoming solar radiation under the clear, polyethylene panels. For example, soil solarisation using clear thin polythene cover for 3-6 weeks in summer—very effective for Root-knot nematode control.

Flooding

Flooding has been shown to suppress nematode populations. Alternating 2 to 3 week cycles of flooding and drying have proven to be more effective than long, continuous flooding cycles. Several cycles of flooding (minimum two weeks) alternating with drying and disking also effective.

Although generally used in small or localised situations, some methods of mechanical/physical control are finding wider acceptance because they are generally more friendly to the environment.

Red Plastic Mulch

Red plastic mulch reflects wavelengths of light that cause the plant to keep more growth above ground, which results in greater yield. Meanwhile, the plant is putting less energy into its root system—the very food the nematodes feed on. So reflection from the red mulch, in effect, tugs food away from the nematodes that are trying to draw nutrients from the roots.

Hot Water Treatment

This method is prevalently used for killing the nematodes inside the propagating materials like seeds, corms, bulbs, tubers and fleshy roots. For example, immersing the seeds in hot water at 45°C for 15 minutes or 50°C for 10 minutes reduces white tip nematode infestations on rice.

Sieving and Winnowing

This method is effectively used to remove the Anguina galls from wheat seed lot.

Biological Control

Biological control is the use of living organisms—parasites, predators, or pathogens—to maintain pest populations below economically damaging levels, and may be either *natural* or *applied.* A first step in setting up a Bio-intensive IPM programme is to assess the populations of beneficials and their interactions within the local ecosystem. This will help to determine the potential role of natural enemies in the managed agricultural ecosystem. It should be noted that some groups of beneficials (*e.g.*, spiders, ground beetles, bats) may be absent or scarce on some farms because of lack of habitat. These organisms might make significant contributions to pest management if provided with adequate habitat.

Natural biological control results when naturally occurring enemies maintain pests at a lower level than would occur without them, and is generally characteristic of biodiverse systems. Mammals, birds, bats, insects, fungi, bacteria, and viruses all have a role to play as predators and parasites in an agricultural system. Creation of habitat to enhance the chances for survival and reproduction of beneficial organisms is a concept included in the definition of natural biocontrol. Applied biological control, also known as "augmentative biocontrol", involves supplementation of beneficial organism populations, for example through periodic releases of parasites, predators, or pathogens. Several microbial pathogens are effective against nematodes. These include the bacteria *Pasteuria penetrans* (formerly known as *Bacillus penetrans), Bacillus thuringiensis*

(available in insecticidal formulations) and *Burkholderia cepacia.* Nematicidal fungi include *Trichoderma harzianum, Hirsutella rhossiliensis, Hirsutella minnesotensis, Verticillium chlamydosporum, Arthrobotrys dactyloides* and *Paceilomyces lilacinus.* Another fungus, *Myrothecium verrucaria,* found to be highly effective in the control of nematodes, is available in a commercial formulation, DiTera™, Prosper-Nema™, Deny™ *(Burkholderia cepacia)* and Activate™ *(Bacillus chitinosporus)* are some of the commercially available microbial biopesticides.

Compatibility of neem products and bioagents for the management of *M. incognita* and *R. reniformis* infecting eggplant (Mojumder *et al.*, 2002)

Treatments	No. of galls	Soil population (per 10 cc soil)	
		M. incognita	*R. reniformis*
Neem seed powder (NSP)	25	125	200
Neem cake (NC)	27	125	250
Paecilomyces lilacinus (PL)	31	150	258
Verticillium chlamydosporium (VC)	32	167	242
NSP + PL	10	100	167
NSP + VC	13	108	208
NC + PL	14	108	192
NC + VC	18	117	208
Control	41	200	375
CD at 1%	0.6	2.9	1.0

The insect-attacking nematode *Steinernema riobravis* can provide root-knot nematode control comparable to that achieved with chemical nematicides. Although the exact mechanisms of control are not known, researchers hypothesize that there is an allelochemical involved (perhaps manufactured by symbiotic bacteria that live within *S. riobravis)* that repels plant-parasitic nematodes. A soil-dwelling predatory mite, *Hypoaspis miles,* preys primarily on fungus-gnat larvae but will also attack spring tails, thrips, and nematodes. It is clear that there is a wide range of organisms that feed on, kill, or repel nematodes. These organisms are most effective, and are found most commonly, in healthy, well-managed soils.

Botanical Nematicides

Certain plants are able to kill or repel pests, disrupt their lifecycle, or discourage them from feeding. Crops like marigolds, sesame, castorbean, and various brassicass are used as nematode-suppressive cover crops.

For hundreds of years, Indian farmers have used the neem tree *(Azadirachta indica)* for its pesticidal, antigungal, and antifeedant properties. Potting soil amended with plant parts from the neem tree and Chinaberry tree *(Melia azadirach)* inhibited root-knot nematode development on tomatoes. Margosan-O™, Azatin™, Superneem 4.5™, Neemix™, and Triact™ are neem products registered as insecticides, fungicides, and miticides. Neem cake, made from crushed neem seeds, provides nitrogen in a slow-release form in addition to protecting plants against parasitic nematodes. It can be mixed with fertilizers such as composted manures, seaweed, and kelp. Neem cake is toxic to plant-parasitic nematodes and not as detrimental to beneficial free-living soil organisms.

Effect of integration of *Glomus mosseae* with *Pasteuria penetrans* on plant growth and *M. incognita* infecting tomato (Rao *et al.*, 1999)

Treatments	Plant height (cm)	Shoot weight (g)	Root weight (g)	Root-knot index	Nematode population in roots
G. mosseae	89.3	21.4	8.6	3.4	142
P. Penetrans	77.6	18.2	7.0	3.1	165
G. Mosseae + *P. penetrans*	91.7	22.7	9.1	2.4	94
Control	65.4	16.6	6.8	4.2	178
CD 5%	8.46	3.23	0.72	0.56	14.57

Current Status of Integrated Nematode Management in India

Indian Agricultural Research Institute, New Delhi

* Developed seed treatment technology with neem seed powder, carbofuran/ carbosulfan in direct seeded crops for management of root-knot, reniform and cyst nematodes.
* Developed an easy and economical management package of ear cockle nematode of wheat.
* Developed soil solarisation technique in nursery beds.
* Developed an economical and eco-friendly medium for mass culturing of nematode antagonistic fungal bio-agents.
* Developed integrated management schedules against root-knot and pigeon pea cyst nematode.

* Established Nematode Disease Diagnostic Clinic to assist and advise farmers.

Indian Institute of Horticultural Research, Bangalore

A concept entitled "Bio-intensive Nematode Management" (BNM) was developed in this institute. The major interventions under BNM are as follows:

Nursery bed treatment (per sq.m.)

* Neem cake/pongamia/castor cake followed by soil solarisation (500 g).
* Formulation of *Trichoderma harzianum* and *Paecilomyces lilacinus* (50 g).
* Endomycorrhizae 100 g. and neem cake 250 g.
* Neem cake 250 g and *Verticillium chlamydosporium* 50 g.
* Fresh Calotropis leaf or Pedilanthus leaf @ 500 g.

Effect of chopped Madar *Calatropis procera* leaves, seed treatment with carbosulfan and triazophos spray on plant parasitic nematodes and yield of groundnut (Prasad *et al.*, 1997)

Treatment	Nematode population/250 cm^3 soil				Yield/5 plants (g)	% increase over control
	Before treatment		After treatment			
	M. Arenaria	*R. reniformis*	*M. Arenaria*	*R. reniformis*		
T_1 = Chopped Madar leaves @ 10 q/ha	140	230	10	24	47	59.04
T_2 = Seed treatment with Carbosulfan 40 STD @ 2% w/w	70	237	33	50	32	7.84
T_3 = Triazophos (40 EC) spray @ 500 ppm (twice)	127	221	20	40	33	11.26
$T_4 = T_1 + T_2$	140	170	53	90	33	13.65
$T_5 = T_1 + T_3$	100	163	20	26	24	–19.45
$T_6 = T_2 + T_3$	167	160	33	113	40	36.51
$T_7 = T_1 + T_2 + T_3$	190	197	10	20	40	37.54
T_9 = Control	213	167	140	230	29	

Main Field Treatment

* Neem based formulation of T. harzianum and P. lilacinus for enriching FYM @ 2 kg + 1 kg neem cake (root-knot, burrowing, citrus nematode infecting Banana, Acid lime, papaya, pineapple and grapes).
* Trap crops mustard and marigold in tomato nursery beds.
* Crop rotation with sunhemp, maize, mustard, marigold and pigeonpea.

Indian Institute of Pulses Research, Kanpur

IIHR, Kanpur major interventions are as follows:

* Intercropping mustard with chickpea (6:2) for ROOT KNOT NEMATODE.
* Cropping sequence of cereals in kharif and chickpea in rabi for ROOT KNOT NEMATODE.
* Neem, Castor, Mahua cakes and poultry manure @ 1 t/ha for mung bean.
* Seed coating with Nimbicidine @ 0.1% in rajmash.

Indian Institute of Spices Research, Calicut

IISR, Calicut recommended some components for Black pepper and Cardamom which were as follows:

* Using VAM isolates in nursery mixtures.
* Soil solarisation.
* Addition of *Trichoderma harzianum* on coffee husk @ 2.5 kg/bed for ROOT KNOT NEMATODE control.

Sugarcane Breeding Institute

Developed Bio-rational Integrated Nematode Management. The other major interventions are as follows:

* Crop rotation with paddy, sun-hemp.
* Fallowing and disking the field before planting.
* FYM or pressmud @ 50 t/ha.
* Pressmud loaded with *T. viride, P. lilacinus.*
* Intercropping with legumes.

Constraints in Implementation of Biointensive INM in India

* Lack of awareness among peasants.
* Non-availability of BINM technologies for many nematodes/crops/locations.
* Deep rooted chemical first concept and dominance of Pesticide Industry.

Effect of the treatments on Yield (Chakraborti, 2001)

Treatments	Yield (ton/ha)
Seedling root dipping in 10% a.i NSKE for 20 minutes	16.5
Neem cake in seed bed @ 2 kg/m^2, in main field @ 300 kg/ha 7 DBT and thereafter once in every 30 DAT	20.1
Neem leaf mulch @ 1.5 kg/m^2 once in every DAT	18.5
Seed bed trap crop—a susceptible brinjal local cultivar	16.6
Turmeric: non-host,antagonistic crop	18.3
Non-host crop—rotation; mustard-sesbania-brinjal	19.4
Stubble burning	16.3
Deep ploughing followed by solarisation	19.1
Flooding for 30 days	18.8
All above Treatments combined	27.2
10 + carbofuran @ 2 kg ai/ha at transplanting and 20 DAT	27.1
Chemical check: seedling root dip in carbofuran at 0.01% ai for 10 min, @ 2 kg ai/ha at transplanting and thereafter once in 20 DAT	24.4
Untreated check	15.5

Sustainable Agriculture and BINM

Sustainable agriculture is a system of agriculture that is ecologically, economically, and socially viable, in the short as well as long-term. Rather than standing for a specific set of farming practices, a sustainable agriculture represents the goal of developing a food production system that:

* yields plentiful, affordable, high-quality food and other agricultural products
* does not deplete or damage natural resources (such as soil, water, wildlife, fossil fuels, or the germplasm base)
* promotes the health of the environment
* supports a broad base and diversity of farms and the health of rural communities
* depends on energy from the sun and on natural biological processes for fertility and pest management
* can last indefinitely.

A premise common to BINM and sustainable agriculture is that a healthy agroecosystem depends on healthy soils and managed diversity. BINM and sustainable agriculture share the goal of developing agricultural systems that are ecologically and economically sound. BINM may be considered a key component of a sustainable agriculture system.

Conclusion

Bio-intensive INM module, that better understands the complex ecologies of soil and agricultural ecosystems can be considered as the most economic, easy to adopt and eco-friendly technology.

References

Ali, S.S. (1997). "Status of nematode problems and research in India." In: *Diagnosis of key nematode pests of chickpea and pigeonpea and their management.* Proceedings of a regional training course, 25-30 Nov., 1996, ICRISAT, Patancheru, pp. 74-82.

Chakraborti, S. (2001). Integrated Management of Root-knot Nematode in Brinjal. *Indian J. Nematol.* **31** (1): 79-98.

Dhangar, D.S., Gupta, D.C. and Jain, R.K. (2002). Studies on intercropping of marigold with brinjal on plant growth and population of root-knot nematode. *Indian J. Nematol.* **32** (2): 183-233.

Dhawan, S.C., Gaur, H.S., Pankaj, Kaushal, K.K., Ganguly, S., Chawla Gautam, Singh, R.V., and Sirohi Anil, (2001). *Indian Nematology—Progress and Perspectives.* National Congress on Centenary of Nematology in India: Appraisal and Future Plans.

Dufour Rex. (2001). Biointensive Integrated Pest Management. www.attra.ncat.org.

Mojumder, V., Dhawan, S.C., Pankaj and Singh, J. (2002). Compatibility of Neem Products and bioagents for the Management of *M. incognita* and *R. reniformis* infecting Egg Plant, *Indian J. Nematol.* **32** (2): 183-233.

Rao, M.S., Reddy, P.P. and Nagesh, M. (1999). Bio-management of *M. incognita* on tomato by integrating *Glomus mosseae* with *Pasteuria penetrans, Indian J. Nematol.* **29** (2): 171-173.

Seghal Mukesh, Dhandapani, A., Niranjan Singh, Trivedi, T.P. and Gaur, H.S. (2004). Nematode Management Information System, *Indian J. Nematol.* **34** (2): 205-238.

Singh Amerika, Sardana, H.R. and Naved Sabir, (2004). *Validated IPM technologies for selected crops*, NCIPM, New Delhi, pp. 6-60.

❑❑❑

15

Nematode Pests of Bast Fibre Crops and Their Management

C.D. Mishra and S.K. Laha

Introduction

The commercial jute fibre is extracted from the bast of tossa jute *(Corchorus olitorius)* and white jute *(C. capsularis).* Fine jute is also obtained from ramie *(Boehmeria nevea), flax (Linum usitatissimum)* and sunnhemp *(Crotalaria juncea), and* coarse jute from crops like mesta *(Hibiscus cannabinus), roselle (H. sabdariffa),* Congo jute *(Urena lobata), Malachra capitata,* sisal *(Agave sisalana)* and Manila hemp *(Musa* sp). To a limited extent fibre is also extracted from leaf petiole of a few types of palm trees and bamboo.

Jute

Jute *(Corchorus* spp), originated from Malaysia or Srilanka, is now a very good cash crop of Eastern India and Bangladesh and also other countries like Brazil, Mexico, Argentina, UAR, Iran, China, Japan, Indonesia, Nepal and a few countries in Central Africa. In India it is grown in West Bengal (0.61m ha), Bihar (0.15 m ha), Uttar Pradesh (25th ha), Orissa (4.8th ha), Assam (75th ha), Tripura (43th ha) and Manipur. Mesta and roselle are grown in Orissa, Andhra Pradesh and in peninsular India and sunnhemp in some pockets in North India.

Tossa jute, which covers maximum acreage is suitable for loam to sandy loam soils of wann humid areas with 24°-35°C temperature and 85 per cent RH, is sown from March to May in medium and uplands. White jute is suitable for early sowing in low lying areas with early rains. The crop is harvested from August to October in its flowering or small pod stage and retting is done under clear water to remove fibre from its bark. Fibre yields per ha. can range from 2.5 to 3 tons from 130-140 day crops under good management practices.

Root-knot nematodes are the most destructive pests of jute one of which was reported from it as early as 1911 by Bessey as *Heterodera marioni.* The species recorded were *Meloidogyne incognita* (Chattopadhyay and Sengupta, 1955), *M. javanica* (Timm, 1959), *M. incognita acrita* (Luc and Guiran, 1960), *M. thamesi* (Mishra and Mandal, 1988), *M. hapla* and *M. graminicola* also.

Other important nematodes recorded are *Pratylenchus brachyrus* (Luc and Guiran, 1960), *P. pratensis* (Johnston, 1960), *P. coffeae* (Mishra and Sasmal, 1988), P. *minius, Helicotylenchus digonicus* (Mishra *et al.*, 1985), *H. dubius, H. dihystera, H. indicus, H. retusus, H. indentatus, H. mucronatus, Hoplolaimus indicus, Tylenchorhynchus masoodi, Rotylenchulus reniformis, Longidorus machramphis, Xiphinema americanum, X insigne, Hirschmanniella oryzae* (Chaturvedi and Khera, 1979), *Hemicriconemoides* sp., and *Scutellonema brachyurum* (Mishra, 1995). *Hirschmanniella* spp. were also recovered from their roots in low land field conditions.

Root-knot Nematode: *Meloidogyne* spp.

These nematodes are prevalent in most of the jute growing tracts of the world including India. In our country *M. incognita* and *M. javanica* are most abundant in the plains (Chattopadhyay and Sengupta, 1955). *M. arenaria* was located in North Bengal and Assam; *M. hapla* was recorded in Europe and *M. thamesi* from Assam. *M. incognita has* been reported from Bangladesh, South East Asia, Latin America and some African countries. They cause more damage in the sandy and sandy loarn soils of North Bengal and Assam than in the new alluvium of the Gangetic plains.

These nematodes may cause loss up to 51.9 per cent in fibre yield (Saikia and Phukan, 1986) in tossa jute. In an inoculated experiment, Mishra and Singh (1985) observed 47 per cent plant damage at an inoculum level of 10 J_2 per seedling. Field damage is influenced by inoculum density, soil type, water regimes, climatic conditions and invasion of secondary pathogens. Overall crop loss in our country has not been methodically estimated so far due to concomitant secondary pathogen infection; but appears on an average to exceed 15 per cent of the final produce each year. When this crop follows another susceptible crop like vegetables, pulses or other fiber crops the initial inoculum remains high and the crop suffers an early attack when it is most vulnerable. From sowing time the crop is exposed to hot sun when the water table is low and root system is short. A nematode attack at this phase of the crop leads to wilting of seedlings and a thin crop stand, leading to smothering by deep rooted weeds, ultimately reducing the yield.

When the initial population at sowing time is low, or when the infection is delayed the extent of crop loss decreases. The extent of loss caused by 10 J_2 at 2 leaf stage can be affected by 100 J_2 to a 15 day old plant and even 10,000 J_2 may not suffice to cause that much damage to a 45 day old plant (Mishra and Singh, 1985). Some times very tall and thick plants are observed with fully galled roots at the time of harvest and hence the observers remark that nematodes are not much of a problem especially in white jute. It is obvious that the nematode population had been below threshold limit at the time of sowing and that most of these galls were caused by third or fourth generation offsprings on a fully established plant in woody roots. However, such plants may die shortly if a disease complex sets in. Bora and Phukan (1982) and Mohsin *et al.* (1989) also observed that significant yield reduction occurred when inoculum density reached 1000 J_2 $Plant^{-1}$

Investigators have ascribed different field symptoms to nematode attack (Chattopadhyay and Sengupta, 1955). Thin populations of seedlings in different patches near the bunds or inside the fields containing stunted plants with smaller and yellowish leaves, which droop as the sun goes up and recover at night but permanently wilt after some days, is a sure indication of the nematode infection. Carefully extracted roots reveal the presence of galls of various sizes that have blocked the passage of water into the stem. The average size of galls formed on white jute is generally greater than those on tossa jute, even though the later is more susceptible than white jute.

In net house pot culture studies it was observed that J_2 of *M. incognita* entered freely in to roots by puncturing the root cap, zone of elongation and up above that in their order of preference (Mishra *et al.*, 1985). Most of them entered in to softer parts within 24 hrs. and some others in to older parts or tap root, or even at the plant base 2-4 days after inoculation. Initiation of giant cell production was observed in 24 hrs after penetration, which was distinguished as a gall on the 4th day. Galls were produced by hypertrophy of the feeding cells in the stele leading to giant cell production and hyperplasia in the pericycle. Cortical cells surrounding the area also increased in size. From the galls males started emerging on 12th day after penetration and egg production started on 15th day in tossa jute which occurred on 13th and 16th days respectively on white jute. Life cycle was completed by 25th day including the embryonic development. Nematodes entering singly in to tender roots developed faster, while those penetrating in a cluster could not form galls; such roots became club shaped without producing giant cells. Some of the juveniles developed to males while most others perished. The J_2 which entered in to older roots lagged behind in inducing giant cells, development in to adults and production of eggs. Malaker and Mian (1994) observed that the life cycle of this

nematode was completed in 20 days in white jute (without embryonic development). Bora and Phukan (1982) found that the rate of multiplication of root knot nematode was the highest when the inoculum was the lowest, *i.e.*, 10 J_2 per pot.

M. arenaria was found (Mishra and Das, 1987) to penetrate in to roots of cultivar JRO-632 in 48 hrs after inoculation causing hypertrophy of feeding cells in 72 hrs. Swelling of the roots was evidenced in 96 hrs and males were able to emerge on 14th day after inoculation. Laying of eggs started from 20th day and 2nd stage juveniles emerged from the 28th day. Hence it is concluded that the life cycle is completed in 27 days at the earliest. By the 40th day many females were observed to have laid 200-350 eggs in their egg masses but egg hatching was limited.

Root knot nematodes have been associated with many fugi, bacteria and other microorganisms to form disease complexes. They are known to have synergistic effect on the development of root rot disease caused by the fungi *Rhizoctonia bataticola* (Mishra *et al.*, 1988) and *Macrophomina phaseolina* (Majumdar and Goswami, 1974; Haque and Mukhopadhyay, 1979 and Begum *et al.* 1990). The fungi caused root rot by itself, but its intensity increased three times when the nematode and fungi were inoculated together near the plant base. The complex disease was more detrimental to the tossa jute than white jute.

Another type of disease complex, better known as Hoogly wilt is caused by the bacterium *Pseudomonas solanacearum* in the presence of either *R. bataticola,* or root knot nematodes or both (Mandal and Mishra, 2001). Another fungus *Fusarium solani* is almost always associated with this disease in field condition, but its role in the complex has not been ascertained. The bacterium inoculated alone in pot culture conditions caused wilting in about 10 per cent of the plants. It damaged 26 per cent plants when the nematode was associated and 35 per cent plants when both nematode and *Rhizoctonia* were associated with it in the plant rhizosphere. Here the nematode served both as a wounding agent and provider of modified substrate in the giant cells. Moreover, the giant cells are known to release nutrients into the rhizosphere thereby facilitating growth and ramification of microorganisms. The natural barrier, root epidermal cells, recognises the sugar coat of the bacterium and resist their entry, which becomes useless when the cuticle is perforated. Finally upon entry, the nutrient rich giant cells provide the substrate needed for quick multiplication of the bacterium and choking of the vascular tissue resulting in the wilt symptom. Saxena, (1972) recorded 9 amino acids in jute roots, which increased to 13 in the root galls of *C. capsularis* induced by *M. javanica.* In the field this disease

spreads very quickly and covers vast areas to cause an epidemic. This disease was first detected in Hoogly district of West Bengal where the crop rotation: jute-potato was followed for years together. Both of these crops are very good hosts of the nematode and the bacterium for which the populations of both the organisms reached above threshold limits in the cropping zone at the time of sowing jute and planting of potato. Another bacterium *Ralstonia solanacearum* has been found to cause disease complex with *M. incognita* in this crop (Hazarika *et al.*, 2003 and 2005).

Control of nematodes in general is difficult in jute due to high atmospheric temperature and hot dry soil in the first half of its growing season and high rainfall in its later part. Dissipation of nematicides to reach the feeder root is difficult in the beginning of the season as the soil is dry because jute is generally grown in unirrigated land. Added to it a sizable part of the chemicals suffer volatilisation in the hot soil before solublisation in water near rhizosphere. Later the rainy season approaches when much of it is lost in leaching and runoff. Hence application of a higher dose of chemicals is essential, rendering it uneconomical for most of the farmers.

Before the introduction of systemic pesticides DBCP was used to control nematodes to a great extent (Tripathy and Bhattacharya, 1969; Srivastava *et al.*, 1971 and Sing, B., 1981). Recently, chemicals like carbofuran, carbosulfan, aldicarb, phorate, ethoprophos, and quinalphos have been used @ 1-2 kg ai.ha^{-1} providing good control of this nematode. Nahar and Mian (1995) observed that seed treatment with carbofuran and isozafos @ 500-1000 ppm decreased gall index and increased crop yield. Carbosulfan also was found to be a good seed treating chemical for management of this nematode (Khan, 2004). Nowadays they are phased out due to their hazardous effects on the environment.

Senapati and Ghosh (1992) found that carbofuran @ 2kg ai ha^{-1} applied 7 days after sowing followed by transplanted paddy; or poultry manure @ 5 tons reduced root knot damage. Organic amendments *viz.* mustard oilcake, poultry manure, saw dust and decaffeinated tea waste @ 0.6% w/w (12 ton/ha) were very effective in reducing nematode damage (Bora and Phukan, 1983). Neem, Karanj, Mahua and mustard cakes used @ 0.5 to I ton/ha also proved to be useful. Roy (1979) was able to reduce nematode infection using decaffeinated tea waste, water hyacinth compost @ 10 tons ha^{-1}, saw dust @ 10 tons ha^{-1}. Chicken manure (litter) used @ 10 ton ha^{-1} was found to reduce nematode population and maximise fibre yield as well (Mishra *et al.* 1987). Presumably production of ammonia during decomposition of tea waste and chicken litter inhibited hatching of eggs and movement of the juveniles but not its root penetration.

Attempts have been made to integrate cultural practices like summer ploughing, removals of stubbles, crop rotation with rice and wheat, application of systemic pesticides and use of organic waste to curb nematode damage (Mishra *et al.*, 1987). Initial population was reduced by application of systemic pesticides (carbofuran/phorate/ quinalphos) @ 1 kg ai ha^{-1} and chicken litter @ 10 ton ha^{-1} in jute. Next season rice cropping induced reduced soil condition, further limiting nematode growth and multiplication and finally in the third season wheat crop reduced them to below threshold limit. Interestingly the cultural practices alone were able to reduce their population below TL by the end of the 2nd year in the new Gangetic alluvium. This practice alone was not useful for reducing the population in the light textured soils of Assam and North Bengal, where both chemicals @ 2 kg ai ha^{-1} and organic wastes @ 10 tons ha^{-1} had to be combined to reach that level of control. In the endemic areas it is better to choose roselle or sunnhemp to jute. Some white jute varieties are tolerant to this nematode, which can be used in crop rotations with paddy. Varieties suitable for early sowing, which can escape the nematode attack in the early season should be grown wherever possible. Chakraborti (2001) also attempted to integrate different components for its management. However, it needs further investigation in order to make it cost effective. Luang and Bora (2005) have arrived at a cheaper method (neem cake @ 1500 kg ha^{-1}) which needs manipulation in its method of application to affect a higher degree of nematode population reduction.

A few varieties of jute were tested for resistance against root-knot nematode but none was promising (Srivastav *et al.*, 1974). Many cultivated and wild jute spp. and most of the white jute germplasm have been tested for resistance against these nematodes. The wild jute species like *Corchorus acutangularis, C. fascicularis, C. tridens, C. trilocularis* have been found to be resistant and a few white jute varieties (ASC 5, Ch Np 25, JRC 185, K 17, K 56, K 57, K 121, Lanka Assam, MGC 2, MGC 4, MGC 6, Mp 86, Taichung 2br, TRC 24, TRC 37, UP 22, UP 37, UP 44) have been found to be tolerant to this nematode (Mishra and Chakrabarti, 1987). Nahar and Mian (1995) and Luang and Bora (2005) also studied the reaction of some varieties but could not find resistance in any one. Fourteen white jute varieties *viz.* CIN *(capsularis* indigenous) 331, 342, 344, 351, 364, 394, 395, 398, 401, 405, 411, 429, 433 and 448 have been found to be resistant to root-knot (Laha *et al.*, 1995). These plants are not good yielders. However, they can be used in breeding programmes for evolving high yielding resistant varieties. Resistance genes can be transferred from wild species to high yielding varieties through modern biotechnological procedures.

Biological control agent *Beauveria bessiana* was found to be very effective in killing most of the tested nematode species in petri dishes in the laboratory, but ineffective in pot cultures in the soil (Laha, *et al.* 1998). *Trichoderma viridae* was effective in reducing galling upto approximately 50% over control. A formulation that can linger their viability and method of application for action in the target site can be useful in affecting a satisfactory level of control.

Reniform Nematode: *Rotylenchulus reniformis*

It is also an important nematode pest of jute that can cause considerable loss under favourable conditions. The young females were observed to enter jute roots between 2nd to 10th day after inoculation (Mishra *et al.,* 1985). They entered above the root tip, in the zones of multiplication, elongation and maturation in that order of preference. During the feeding period their head remained embedded in the cortical zone while the rest of its body remained outside in soil. Near its head region an almost spherical feeding zone was observed surrounded by a group of 6 to 10 cells, which were hypertrophic, thick walled and filled with dense cytoplasm. This structure connected the nematode to the pericycle through the helical feeding tube. The posterior part of the nemas started swelling 2 days after penetration and the egg sac appeared after 7 days. At 14 days they assumed kidney shape and were completely enveloped by the egg sac. On the 20th day some females were found to have deposited 15-20 eggs in the sac. Beyond that period fecundity was found to be 5-10 eggs per day which extended up to 45 days after penetration. But the number of eggs in the egg sac never exceeded 50 which indicated that there was continuous hatching out probably from 8th to 10th day after laying (embryonic development).

In many other crops reniform nematode is known to cause disease complexes with *fungi (Rhizoctonia* sp, *Verticillium* sp and *Fusarium* sp) and bacteria *(Pseudomonas)* to cause a greater loss. The same organisms are also found to cause diseases in jute. Further investigations will explain their relationships in causing disease complexes in jute plant. Procedure for the management of this pest in jute has not been worked out. A few experiments have to be conducted on this aspect to evolve suitable management practices for this nematode in jute.

Lesion Nematode: *Pratylenchus* spp.

Lesion nematodes recorded in white jute are *P. brachyurus, P. pratensis* (Johnston, 1960) and those in tossa jute are *P brachyurus and P. coffeae* (Mishra and Sasmal, 1988). These are ubiquitous, found in all the jute growing countries *viz.* India,

Indonesia, Bangladesh, Philippines, Congo, Central Africa, USA, Brazil and Latin America. In India they are found in all the states, where they are known to infect banana, citrus, coffee, cereals, pulses, vegetables, ornamentals, fruits and fibre crops like jute and many other plant types.

Pratylenchus coffeae was found to be highly pathogenic to jute (Mishra and Sasmal, 1988). Populations as low as 2 nemas per seedling at the 2 leaf stage caused considerable loss to plants leading to wilting. Juveniles and adults of this nematode reached inside the growing part of the roots in 24 to 48 hrs after inoculation and fed on the cortical cells. Cortical tissue fed upon formed lesions within 2 days. Nematodes migrated to fresh areas to feed and lay eggs thus covering between 5 to 10 mm of root per week. When two or more nematodes entered the young tap root, it collapsed and ultimately died of wilting after 10-14 days. This nematode was found to complete its life cycle in 27 days within the root. This nematode has the capability to produce complex diseases with fungi *R. bataticola* and *P. solanacearum* in the field conditions. Management procedures have not been worked out for this nematode in jute. Hence the practices followed to manage them in other crops may be followed here after due consideration, until specific procedures are evolved.

Lance Nematode*: Hoplolaimus indicus*

This was recorded in jute in 1959 by Timm and subsequently in West Bengal by Banerjee and Banerjee in 1966. This is also a polyphagus pest attacking cereals, pulses, vegetables and fibre crops including jute. It is available in almost all soil samples counting up to 55 per 250 ml (Laha *et al.,* 1988). Total loss caused by this nematode to jute has not been accounted for, but its mode of feeding both as ecto and endo parasite and ftequent migration from soil to root tissue and vice versa exposes the root cortex to other microorganisms. Management practices of this nematode have not been attempted.

In pot culture experiments both adults and juveniles have been found feeding on jute roots above the zone of elongation, or even on matured roots ectoparasitically, puncturing the cuticle (Mishra *et al.,* 1985). From the 3rd day onwards some of them, mostly females and juveniles started penetrating and migrating in to the cortex. They moved intercellularly in the cortex feeding on adjacent cells. A few of them were found to move out into soil at different periods. Cortical cells collapsed when the nemas moved inside which turned necrotic later. Eggs were laid both inside the root and in soil. The nematode was found to cause disease complex in the presence of the fungus *Macrophomina phaseoli* (Haque and Mukhopadhyay, 1979).

Crop rotation or changing a variety has no impact on its population as this nematode is polyphagus in nature. Antagonistic crops like *Tagetes, Asparagus and Crotalaria* can reduce its population to some extent. Management practices using organic amendments, biological control agents are not yet available. In problem areas systemic nematicides may be used @ 1-2 kg ai. ha^{-1}.

Scutellonema brachyurum

This nematode was found to attack jute roots in Assam (Mishra, 1995). It is an endoparasitic nematode feeding on root cortex producing lesions, which is less severe as compared to lesion nematode. This nematode is also found to attack ramie, mesta, babana and many other cash crops including rice.

Spiral Nematode : *Helicotylenchus* spp.

Many species of spiral nematodes *viz. H. indicus, H. dihystera, H. retusus, H. indentatus, H. mucronatus* and *H. digonicus* have been recorded on jute roots (Chaturvedi and Khera, 1979; Mishra *et al.,* 1985). Authors encountered one species or the other during their survey work (Laha *et al.*, 1988) in each soil sample. Their populations reached 72 per 250 ml soil in some locations. In pot culture experiments juveniles and adult females of *H. digonicus* were observed feeding on jute roots both ecto and endoparasitically (Mishra *et al.,* 1985). Its mode of feeding, migration and egg laying were similar to that of lance nematode as described above. But its population was not affected by antagonistic crops *like tagetes,* sunnhemp or *asparagus.*

Other Nematodes

Tylenchorhynchus masoodi, Longidorus machramphis, Xiphinema americanum, Xinsigne, Hemicriconemoides sp. feed upon jute roots ectoparasitically, but their feeding symptoms or control measures have not been investigated yet.

Mesta (Kenaf)

This crop is grown in India, China, South East Asia, Latin America and some African countries for using as fibre or making paper. This is suitable for growing in drier climates as compared to jute.

Mesta is susceptible to *Meloidogyne* spp. (Ayyar, 1931), *M. arenaria* (Sasser, 1954), *M. arenaria thamesi* (Linde *et al.,* 1959), *M. hapla* and *M. incognita* (Tharnes *et al.,* 1952), *M. incognita acrita* and *M. javanica* (Sasser, 1954), *Helicotylenchus multicinctus, Pratylenchus brachyurus* (Sher *et al.,* 1953), *Hoplolaimus indicus, Helicotylenchus dihystera* (Laha *et al.,* 1988) and *Telotylenchus historicus.*

Root knot nematodes cause considerable damage to mesta and their damage symptoms are similar to that of jute. Some of these nematodes are known to cause complex disease in combination with *Sclerotium rolfsii* and cause devastation in the field. No resistant varieties are available in mesta for the root-knot nematodes. However, interspecific hybrids hold some degree of promise in this regard. Methods of nematode management as described in jute hold good for mesta also.

Roselle

It is grown for fibre or paper pulp in drier climates in kharif (rainy) season. Nematodes like *M. arenaria, M. javanica* (Martin, 1958), *M. incognita acrita* (Luc and Guiran, 1960), *Hoplolaimus indicus* and *Helicotylenchus dyhestera* (Laha *et al.,* 1988) have been recorded in roselle. Malaker and Mian (1994) found S 24 variety to be resistant to root-knot. Laha and Pradhan (1987) found a variety, HS 4288 resistant to its attack. But this plant is known to be resistant to nematodes in general and to root-knot in particular.

Sunnhemp

Nematode pests recorded on this crop include *M. arenaria thamesi, M. hapla, M. incognita acrita* (Linde and Clemston, 1956), *Heterodera glycines, Pratylenchus brachyurus* (Luc and Guiran, 1960), *P. coffeae* (Fluiter and Mulholland, 1941), *P. vulnus* (Jensen, 1953), *R. reniformis* (Peacock, 1956), *Helicotylenchus* spp., *Helicotylenchus digonicus* and *Hoplolaimus indicus* (Bandopadhyay and Mishra, 1985). However the variety K-12 yellow of this crop is known to be resistant to root-knot nematode *M. incognita* and a poor host of some nemas reported here (Bandopadhyay and Mishra, 1985).

Sunnhemp is an established nematode resistant crop, though many nematodes were found to be associated with it (Ayala, 1962). A cultivated variety K-12 yellow was inoculated with *M. incognita, Hoplolaimus indicus* and *H. digonicus* and observed periodically. The population of the former was drastically reduced, while the number of the other two decreased to different degrees (Bandopadhyay and Mishra, 1985). This sort of reaction is attributed to the excessive CO_2 accumulation in its rhizosphere and highly vacuolated cells in its root cortex. *C. juncea* is useful as a trap crop for reducing the population density of soybean cyst nematode *Heterodera glycines* (Kushida *et al.,* 2003). *C. spectabilis* is also known to be antagonistic to root-knot nematodes.

Ramie

This is a perennial shrub, bush like in appearance, which under good management practices yields best quality fibre with regard to strength and fineness that

can be blended with synthetics. In India it is grown in North Eastern States and to a limited extent in the Western Ghat areas of Maharashtra.

This plant is infected by many nematodes like *M. incognita* (Mandal, 1979), *M. thamesi* (Mishra and Mandal, 1988), *Pratylenchus elachistus* (Steiner, 1949), *P. brachyurus* (Luc and Guiran, 1960), *P. coffeae* (Fluiter and Mulholland, 1941), *Scutellonema brachyurum, Helicotylenchus mucronatus* (Mishra and Mandal, 1988), *Hoplolaimus indicus, Xiphinema* sp. and *Paralongidorus* sp. (Mishra, 1995).

M. thamesi is the most destructive pest of this crop, which multiplies year after year on its roots and rhizomes, which are exhausted within 3-4 years. The plantation becomes uneconomic by the 5th year. Even if such a field is freshly reclaimed it does not support a new plantation. The field should be brought under rice crop or kept fallow for at least 2 years before planting ramie again. An experiment was conducted here incorporating systemic pesticides, mustard oil cake, saw dust and *Tagetes.* Nematode galling was not reduced to a comfortable level, probably due to high rainfall, that washed and leached the active principles of these inputs, before they acted upon nematodes (Mishra, 1995).

As a precautionary measure, before planting ramie the field should be properly surveyed for the presence of this nematode. It should not be present in the planting materials and proper quarantine should be followed during its growth period.

Sisal

It produces coarse but strong fibre in its leaves, which is suitable for making ropes. Its fibre is resistant to weathering and hence can endure marine use. It is grown in the dry- and wastelands of Deccan. Root-knot nematode (Brown, 1948), *M. incognita* (Anonymous, 1957) and *M. javanica* (Mumford, 1963) have been recorded to attack this plant as per observations in quarantine centres. Detailed survey work has not been undertaken to identify its nematode problem. But it is considered to be a hardy plant inviting lesser nematode attack.

Flax

It is an oilseed crop in our country, which is grown for its fibre in temperate countries. Now it is grown for fibre in Himachal Pradesh and Kashmir also. A lot of work has been done on flax nematodes in foreign countries.

Nematodes recorded in this crop include *M. incognita* (Colbran, 1958), *M. hapla, M. thamesi, M. incognita acrita, M. javanica* (Linde and Clemston, 1956). *Belonolaimus*

longicaudatus, Pratylenchus brachyurus, P. penetrans, P. zeae (Sigareva, 1971), *P. coffeae* (Colbran, 1958), *Ditylenchus dipsaci, Rotylenchulus reniformis, Tylenchorhynchus brevidens, T. maximum, T. phaseoli, Longidorus maximum, Hoplolaimus indicus, Helicotylenchus dihystera* and *Hemicriconemoides* sp. (Laha *et al.*, 1988).

Pathogenicity of *M. hapla* and *P. penetrans* have been established on this crop. Moreover *M. hapla* causes complex disease in combination with *Fusarium oxysporum* f. sp. *lini* and *P. penetrans* does so in combination with *Verticellium* sp. (Coosemans, 1979).

Control measures include the use of systemic pesticides used @ 1 or 2 kg ai ha^{-1}.

Congo Jute

This crop is not grown commercially in our country but has a good potentiality. It is also affected by many nematodes including *M. incognita acrita* (Luc and Guiran, 1960), *M. javanica* (Colbran, 1958), *Hemicycliophora pauciannulata, Scutellonema bradys, Xiphinema attorodorum* (Luc and Hoestra, 1960), *Radophilus similis* (Brooks, 1955), *Rotylenchulus reniformis* (Ayala, 1962), *M. incognita, Hoplolaimus indicus,* and *Helicotylenchus dihystera* (Laha *et al.,* 1988). Information on their control aspects is lacking.

Malachra Capitata

This crop has coarse and strong fibre but is not grown in India now. This crop is resistant to nematode attack. Till now only *Hoplolaimus* indicus has been recorded from this plant (Laha *et al.* 1988).

Conclusion

All these bast fibre crops have not received the attention of research workers till now, though the task is enormous. Workers attending this job are very few and far between. Crop loss assessment, disease complexes and management aspects need immediate attention. Use of biological control agents, effective cultural practices including crop rotation should be given due importance. Resistant varieties should be evolved using biotechnological procedures.

Extension workers should make farmers conversant with these problems and their management procedures in order to avoid losses.

References

Anonymous, 1957. Border of interceptions. *Can. Inst. Pest Rev.* **35** (6): 267.

Anonymous, 1970. Efficacy of some nematicides in the control of nematodes. *Ann. Rep.* J.A.R.I.: 43-44.

Anonymous, 1972. Studies on Hoogly wilt. *Ann Rep.* J.A.R.I.: 70.

Ayala, A. 1962. Green house tests with nematicides for control of nematode attacking *tomato (Lycopersicon esculentum* var. Rutgers) in Puerto Rico. *J. Agric. Univ., Puerto Rico* **46** (4): 319-323.

Ayyar, P.J.K., 1931. Parasite Host List. *Imp. Bur. Agric.* q.v.

Bandopadhyay, A.K. and Mishra, C. 1985. Resistance in some sunnhemp variety against infection of three plant parasitic nematodes. *Ann. Agric. Res.* **6** (1): 98-103.

Banerjee, S. N. and Banerjee, D.K. 1966. Occurrence of nematode, *Hoplolaimus indicus* in West Bengal. *Curr. Sci.* **35** (23): 597-598.

Barrons K.C. 1940. Root knot resistance in beans. *J. Hered.* **31**: 35-38.

Bessey, E.A. 1911. Root knot and its control. *Bull.Bur.Pl.Ind. US. Dept. Agric.* 217, 89 p.

Begum, H., Sultana, K. and Ahmed, N. 1990. Disease development in jute due to the interaction of fungal pathogens *(Macrophomina phaseolina and Rhizoctonia solani)* and root knot nematode *(Meloidogyne* spp) and its effect on yield of fibre and seed. *Bangladesh J Jute Fbr. Res.* **15** (1): 35-40.

Bora, B.C. and Phukan, P.N. 1982. Studies on the pathogenicity of root knot nematode, *Meloidogyne incognita* on jute. J. *Res. A.A. U.* **3** (2): 176-180.

Bora, B. C. and Phukan, P.N. 1983. Organic amendments for the control of root knot nematodes in jute. *J. Res. A.A.U.* **4** (1): 43-50.

Brooks, T.L. 1955. Additional hosts of burrowing nematodes in Florida. *PL Dis. Reptr.* **39** (4): 309.

Brown J.G. 1948. Root knot in Arizona. *Bull. Ariz. Agric. Expt Sta.* 212, 40p.

Chakraborti, S. 2001. Integrated management approach for root knot nematode in jute. *Indian J Nematol.* **31** (1): 44-46.

Chattopadhyay, S.B. and Sengupta, S. K. 1955. Root knot disease in jute in West Bengal. *Curr. Sci.* **24** (8): 276-277.

Chaturvedi, Y. and Khera S. 1979. Studies on Taxonomy, Biology and Ecology of Nematodes Associated with Jute Crop. *Tech Mon.* No. 2. ZSI, Kolkata, India.

Colbran, R.C. 1958. Studies of plant and soil nematodes. 2. Queensland host records of root knot nematodes *(Meloidogyne spp.). Qd. J Agric Sci.* **15** (3): 101-136.

Coosemans, J. 1979. In Proceedings of 2nd International *Verticillium* Sympossium. Univ. Calif, Berkley. *Parasitica,* **35**: 63-72.

Daulton, R.A.C. 1955. Progress reports on eelworm control experiments. *Rhod Tob.* **11**: 21-24

Fluiter, H. J. De. and Mullholand, J.J. 1941. Gegevens verkergen bij het onderzoek naar de waardplanten van *Tylenchus coffeae*. *Bergcultures,* **15**: 88-1593.

Goody J. B., Franklin, M.T. and Hooper, D.J. 1965. *The Nematode Parasites of Plants Catalogued under their Hosts*. Farnham Royal, England., CAB., 214p.

Haque, S. and Mukhopadhyay, M.C. 1979. Pathogenicity of *Macrophomina phaseoli in* jute in the presence of *Meloidogyne incognita and Hoplolaimus indicus. J. Nematol.* **11** (4): 318-321.

Hazarika, K., Rahman, M.F. and Bora, L.C. 2003. Interrelationship of *Meloidogyne incognita and Ralstonia solanacearum* on jute. *J Phyto. Res.* **16** (2): 191-194.

Hazarika, K., Rahman, M.F. and Bora, L.C. 2005. Interrelationship of *Meloidogyne incognita and Ralstonia solanacearum* on jute; its effect on the resultant nematode population. *Res. on Crops.* **6** (1): 165-169.

Helaly, A. F., Abo el Dahab, M.K. and Mehiar, F.A. 1967. Interaction of *Meloidogyne javanica* (Treub) Chitwood. and *Fusarium* wilts of flax and Deccan hemp plants in United Arab Republic. *Phytopath. Medit.* **6**: 57-64.

Jensen, H. J. 1953. Experimental greenhouse host range studies of root lesion nematodes, *P. vulnus and P. penetrans. PL Dis. Reptr.* **37** (7): 384-387.

Johnston, A. 1960. A supplement to a host list of plant diseases in Malaya. Corn. Myc. Inst. Kew. Survey. Mycological papers, No. 77.

Khan, M.R. 2004. Chemical approach for managing root knot nematode , *Meloidogyne incognita* race-2 infecting jute. *NematoL Medit.* **32** (2): 195-199.

Kushida, A., Suwa, N., Ueda. Y. and Momoto, Y. 2003. Effects of *Crotalariajuncea and C spectabilis* on hatching and population density of soybean cyst nematode *Heterodera glycines* (Tylenchida, Heteroderidae). *AppL Ento. Zool.* **38** (3): 393-399.

Laha, S. K., Mandal, R. K. and Dasgupta, M.K. 1995. Screening of white jute *(Corchorus capsularis)* germplasms against *Meloidogyne incognita. Nematol. Medit.* **23** (1): 52-53.

Laha, S.K., Mishra, C.D. and Pradhan, S. K. 1998. "Nematode pests of bast fibre crops and their management." Chapt. 22 in *Nematode Disease of Plants*. Ed. P.C. Trivedi, CBS Publishers New Delhi. 369-377 pp.

Laha S.K. and Pradhan, S.K. 1987. Susceptibility of bast fibre crops to *Meloidogyne incognita. Nematol. Medit.* **15**: 163-164.

Laha, S.K., Singh, B. and Mishra, C. 1988. Plant parasitic nematodes and their population fluctuation associated with jute and allied fibre crops. *Environ. And Ecol.* **6** (1): 100-102.

Linde, W.J. and van der, C. 1956. The *Meloidogyne* problem in South Africa. *Nematologica,* **1** (3): 177-183.

Linde, W.J., van der Clemston, J.G. and Corus, M.E. 1959. Host parasite relationship of South African root knot eelworms. *(Meloidogyne* spp.) *Sci. Bull. Dep. Agric. Tech Serv. Un. S. Afr.* **385**: 1-16.

Luang, B. and Bora, B.C. 2005. Integrated approach for the management of *Meloidogyne incognita on jute. Indian J Nematol.* **35** (1): 50-52.

Luang, B. and Bora, B.C. 2005. Screening of jute cultivars for resistance against root knot nematode, *Meloidogyne incognita.Indian J NematoL* **35** (1): 90

Luc, M. and Guiran, G.De 1960. Les nematodes associes aux plantes de loust African. Liste preliminaries *Agron. Trop. Nogent* **15** (4): 434-449.

Luc, M. and Hoestra, H. 1960. Les nematodes phytoparasites des sols de cocoteraie de Togo. Essai dinterpretation du peuplement. *Agron Trop. Nogent.* **15**: 497-512.

Majumdar, A. K. and Goswami, B.K. 1974. Studies on the interaction of a fungus, *Macrophomina phaseolina(Maubl)* Ashby and root knot nematode *Meloidogyne incognita* (Kofoid and Vvhite) Chitwood in jute *(Corchorus capsularis L.). Labdev J Sci. Tech.* India. **12**(B)2: 64-66.

Malaker, P.K. and Mian, I.H. 1994.a. Susceptibility of some common varieties of jute, kenaf and roselle to root knot nematode *(Meloidogyne incognita). Bangladesh J Sci Indst. Res.* **29** (2): 71-79.

Malaker, P.K. and Mian, I.H. 1994.b. Observation on the life cycle of root knot nematode *(Meloidogyne incognita)* in jute. *Bangladesh J Sci Indst. Res.* **29** (4): 93 -99.

Mandal, B.C. and Mishra,C. 1988. Soil nematode population as influenced by intensive cropping and manuring on long term basis. *Indian J Nematol.* **18** (2): 295-298.

Mandal, R. 1979. Occurrence of *Meloidogyne incognita* on ramie. *Ann Rep.* JARI. 174.

Mandal, R.K. and Mishra, C.D. 2001. Role of different organisms in inducing Hoogly wilt symptom in jute. *Environ. Ecol.* **19** (4): 969-972.

Martin, G.C. 1958. Root knot nematodes *(Meloidogyne* spp) in the Federation of Rhodesia and Nyasaland. *Nematologica.* **3** (4): 332-349.

Mishra, C. 1995. "Nematode Problem of Jute and Allied Fibre Crops." In: *Nematode Pest Management. An Appraisal of Eco-friendly Approaches.* Nem. Soc. of India 211-216.

Mishra, C., Bhattacharjee, A.K. and Pradhan, S.K. 1988. Nematode infection in *olitorius* jute as influenced by water soluble vitamins. *Envi. Ecol.* **6** (4): 1030-1031.

Mishra, C. and Chakrabarti, N. K. 1987. Screening of jute *(Corchorus capsularis)* gerrnplasms against root knot nematode *Meloidogyne incognita* (Kofoid and White) Chitwood *Ann Agric. Res.* **8** (1): 59-63.

Mishra, C. and Das, L.K. 1987. Root knot nematode *Meloidogyne arenaria (Neal)* Chitwood a new pest of jute in North Bengal. *Sci. Cult.* **53**: 127-129.

Mishra, C. and Mandal, R. 1988. Occurrence of *Meloidogyne thamesi and Helicotylenchus mucronatus* on ramie, *Boehmeria nevea L. Indian J Nematol.* **18** (1): 114.

Mishra,C. and Sasmal, B.C. 1988. Pathogenicity of *Pratylenchus coffeae* on jute. *NematoL Medit.* **16**: 153.

Mishra, C. and Singh, B. 1985. Pathogenicity of *Meloidogynejavanica* (Treub) Chitwood *on jute Corchorus spp. Indian J Nemtol.* **15** (2): 245-246.

Mishra, C., Singh, B. and Chakrabarti, N.K. 1985. Host parasite relationship of some nematode pests with jute *(Corchorus capsularis and C. olitorius). Ann. Agric Res.* **6** (2): 162-167.

Mishra, C., Singh, B. and Laha, S.K. 1987. Integrated approach for root knot nematode management in jute. *Indian J Nematol.* **17** (2): 285-287.

Mishra, C., Som, D. and Singh, B.1988. Interaction of *Meloidogyne incognita and Rhizoctonia bataticola* in white jute *(Corchorus capsularis). Indian J Agric. Sci.* **58** (3): 234-235.

Mohsin, M., Mian, I.H., Zahid, M.I. and Ali, M. 1989. Inoculum level of *Meloidogyne incognita* on severity of root knot and growth of jute and potato. *Bangladesh, J PL Path.* **5** (1): 13-17.

Mumford, B.C.1963. *List of integrated plant pests.* US Dept. Agric. Agric. Res Serv. Plant Quarant. Div. 88p.

Nahar, M.S. and Mian, I.H. 1995. Effect of seedling age on development of *Meloidogyne incognita* in jute and allied fibre crops and seed treatment to control root knot of *jute. Bangladesh J Sci Inclst. Res.* **30** (4): 31-42.

Peacock, F.C. 1956. The reniforrn nematode in Gold Coast. *Nature.* London, **177**: 489.

Roy, A.K. 1979. Control of root knot of jute with decaffeinated tea waste and water hyacinth compost. *Indian Phytopath.* **32** (3): 365-368.

Roy, A. K. 1983. Comparison of efficacy of decaffeinated tea waste with nemagon on the control of root knot nematode on jute. *J Res. A. A.* U **4** (1); 63-64.

Saikia, D.K. and Phukan, P. N. 1986. (a) Estimation of loss in jute due to root knot nematode *Meloidogyne incognita. Indian J Nematol.* **16** (1):108-109.

Saikia, D.K., and Phukan P.N. 1986. (b) Effect of crop rotation on the development of root knot nematode, *Meloidogyne incognita* on jute crop. *Indian J NematoL* **16** (1): 110-111.

Sasser, J.N. 1954. Identification and host parasite relationship of certain root knot nematodes *(Meloidogyne spp.). Bull. Md. Agric. Exp. Stn.* A-77 (Tech): 31 p.

Saxena, A.P. 1972. Studies on free arnino acid content in *Meloidogyne javanica,* Treub and in root knot of jute plant. *Zeitschrifffurparasitenkunde.* **40** (2): 101-105.

Senapati, S. K. and Ghos, S.K. 1992. Integration of different means of root knot nematodes *(Meloidogyne* spp) management on jute *(Corchorus capsularis L)* under natural field condition. *Crop Res.* (Hissar) **5** (3): 559-564.

Sher, S. A. and Allen M.W. 1953 . Revision of the genus *Pratylenchus* (Nematoda, Tylenchidae). *Univ. Calif Pub. Zool.* **57** (6): 441-470.

Sigareva, D.D. 1971. *Trudv. Gel. Minthologischoskoi Laboratorii.* **21**: 208-213.

Singh, B. 1981. Pests of jute and mesta and their control. *Jute Dev. J.* **8**: 18.

Srivastava, A.S., Verma, R.S. and Ram, S. 1971. Control of root knot nematode *(Meloidogyne javanica)* with DBCP in jute crop. *Labdev J Sci. Tech.* India. **9B** (3): 206-208.

Srivastava, A.S., Verma, R.S. and Ram, S. 1974. Susceptibility of jute varieties to root knot nematode, *Meloidogyne javanica.* (Treub, 1885) Chitwood, 1949. *Indian J Nematol.* **2** (2):198-199.

Steiner, G. 1949. Plant nematodes the grower should know. *Proc. Soil Sci. Soc Fla.*,**4-B**: 72-117.

Thames, W.H., Sealo, C.C., Gomstad, E.O. and Pate, J.B., 1952. Preliminary reports of some of the disease and pest problems of kenaf. *Hibiscus canabinus* L. in South Florida. IV, V, VI. *PI. Dis. Reptr.* **36** (4): 125-126.

Timm, R.W. 1959. Nematodes associated with wilting of jute. *Pak J Biol. Agric. Sci.* **2** (1): 39-41.

Tripathy, R.L. and Bhattacharya, S. P. 1969. Root knot nematodes in jute. *All Ind Nem. Sympo.*, IARI,: 40.

❑❑❑

16

Strategies of Phytonematode Management in Cereal-Wheat—A Report

Dr. A.K. Singh

Introduction

The All India Co-ordinated Wheat and Barley Improvement Project (AICW & BIP) came in to being in 1965. This was one of the first organised projects initiated by the Indian Council of Agricultural Research which laid the foundation of organised scientific and co-ordinated research under its purview in the 1960s, when a disease problem called locally as Molya in Rajasthan was found to be caused by a nematode parasite, *Heterodera avenae*. Initially, the work started at the Indian Agricultural Research Institute, New Delhi as a voluntary centre to undertake research on the plant parasitic nematodes associated with wheat crop. Subsequently, centres at Jaipur and Udaipur in Rajasthan state, Hisar in Haryana State, and Ludhiana in Punjab state were organised as part of the co-ordinated project to carry out nematological research on wheat and barley nematodes. At present, 5 voluntary centres namely, NDUAT Faizabad, Anand Agricultural University, Anand, RAU Pusa Samastipur, IARI New Delhi and SKAUST Jammu are actively participating in this programme. The main stress now is on Molya (CCN), Ear Cockle (ECN), other plant parasitic nematodes in different wheat based cropping system and their integrated management. More than 25 species of plant parasitic nematodes have been recorded on wheat in India and of these six are endoparasitic and the rest are ectoparasitic.

In spite of fact that a large number of nematodes regularly being encountered in the rhizosphere of wheat crop, only 2 species, *Heterodera avenae* and *Anguina tritici* are economically important; four species *Meloidogyne javanica, M. incognita, Pratylenchus thornei* and *Tylenchorhynchus vulgaris* are of potential importance while role of the rest of the species has not been investigated so far, may be in nutrient recycling.

But now, *M. graminicola* is coming on wheat in other part of the country also.

Pratylenchus and *Tylenchorhynchus vulgaris* are of the potential importance while role of the rest of the species has not been investigated so far in our context. The progress achieved with the important species is therefore, dealt with.

Though Molya was first recorded in 1958 still many aspects are being tackled even today. The progresses achieved with important nematodes are dealt with hereunder.

Biotype Studies of CCN—An Attempt

Exploiting identified and possibly of other as yet unidentified sources of resistance in wheat is country specific and primarily dependent on *Heterodera avenae* and its pathotypes that need to be controlled. Many developing countries unfortunately have limited resources and/or expertise to establish this information, and current control methods are based on the understanding the response of local cultivar to the pathogen. In order for cultivar resistance to be effective and desirable, a sufficient understanding of the number of species and pathotypes within species is essential. The international cereal test assortment for defining cereal cyst nematode pathotypes from Australia and India are often distinct from these in Europe. Although useful, a pathotype scheme for a species complex based on interaction with these cereal genera will not easily describe extensive variation in virulence. Furthermore, to date there are few molecular or other diagnostic methods that can provide consistent and reliable pathotype and pathogenically differentiation. Any how, the traditional approach is still employed as being convenient and reliable.

It was observed in 1995-96 that Sirsa and Mahendragarh (both in state of Haryana, India) population behaved differently indicating the presence of more than one biotype of *Heterodera avenae*, which confirmed the finding of 1994-1995. The Silver Index and Siri differentials yielded susceptible reaction on Sirsa population and resistant reaction on Mahendragarh population. Whereas on Emir both gave susceptible reactions. In 1996-97, Sirsa population was designated as biotype II and Mahendragarh population as biotype I whereas Ambala population was different than both. During 1998-99, it was reported that in Haryana 2 biotypes exist, one is of Sirsa and other of Mahendragarh. Punjab population was different as compared to Rajasthan and Southern Haryana. Delhi centre also proved that Sirsa population was a different biotype besides 2 other known biotypes. In 1999-2000, *H. avenae* in Rajasthan did not differ in its attributes. Sirsa, Mahendragarh and Ambala populations were different among themselves whereas, Punjab was altogether different. But the year 2000-01 exhibited that Jaipur and Udaipur population were different in their reactions on some of the differentials like AUS 15854

(Wheat), Ortolan (Barley), KVL 191 (Barley), Ogalistische (Barley), Dalmastische (Barley), P 31322-1, Martin 403-2 (Barley), L-62, and Nidar II (Oat). Later on, it was established that Sirsa population was different than Mahendragarh.

The year 2001-02 showed that reaction of population of Haryana on differentials differ from earlier report of Haryana in that it gave resistant reaction on Emir, and Capa and susceptible reaction on IK2 Light (Wheat). It is similar to Ambala population in its reaction on Siri, KVL 191 (Barley), Dalmastische and Psathias (Wheat). In the year 2002-03, Hisar and Sirsa populations gave susceptible reaction on Rika, Herta, Varde, Loros, Psathias, and Capa and resistant reaction on rest of the differentials. Hence, they are similar in virulence and belong to same group of pathotypes.

During 2003-04, Hisar population's reaction resembled with Sirsa and Mahendragarh populations. When subjected to biochemical tests Hisar, Sirsa and Mahendragarh populations could easily be distinguished from Ambala population on the basis of isozyme profile of MDH of white females. The earlier chemical studies based on catalaze beta esterase and acid phosphatase enzymes were not able to separate these populations. In Haryana (as arrived at from earlier studies) 2 distinct populations are present now. The population present in Ambala, and in adjoining districts and areas (Panchakula and Morni hills) is different and identified as *H filipjevi*. In Rajasthan, Hanumangarh population is different than biotype I which is found around Jaipur of Rajasthan.

In 2004-05, it was again proved that Mahendragarh, Sirsa, and Hisar had *Ha 21* population of *H avenae* whereas, Ambala and Panchakula had *H filipjevi*. The differentials AUS 15854, AUS 7869, AUS 15895, Harlan 43, Ogalistische, Dalmastische, Emir, Morocco, Gellion, Martin, La estanzuella, L 62, Siri, Drost, and Nidar II supported least/nil population build up of CCN, thus, proving that the population is resistant and different. Moreover, on AUS 498, AUS 15807, Loros, Iskamish K2 Light, Psathias, Capa, P 31322-1, Varde and Herta, the CCN population multiplied in substantial number thus, exhibiting itself as different group within CCN. In Rajasthan, CCN population adjoining Jaipur is different than Hanumangarh as has been repeatedly proved.

Tillage Options and Its Impact

Farmers are accepting conservation tillage due to economics of time and other resources. Survey conducted in 7 rice fields belonging to farmers' cooperators of the project. In each field, rice root and soil samples were collected at random right after harvest. Each sample was made of one hill and 200 cm^3 of rhizosphere soil. The loss of

many nematicides due to environmental concerns and high costs of pesticides registration has focussed considerable attention on the development of cropping schemes that utilise biocontrol agents, green manure crops, resistant cultivars and non-host crops for managing nematodes in both agronomic and horticultural crops. The progress made by many projects in the discovery, identification, culture and evaluation of field efficacy of several strains of biocontrol agents contributed to the development of urgently needed biocontrol agent that will be useful over large acreage. The use of antagonistic cover and rotational crop and compost application were demonstrated to the beneficial in reducing population of RKN and RLN. Host resistance to plant parasitic is one of the most inexpensive, environmentally friendly and feasible methods for managing plant parasitic nematodes in crop plants. Integration of host resistance with biocontrol antagonistic cover and rotational crops and compost application will contribute to the development and implementation of environmentally safe, alternative management strategies for plant parasitic nematodes. Reaction of cover and rotational crops and resistance crops to plant parasitic nematodes will be characterised. Experiments to evaluate cover crops, compost and green manure treatments, and rotational crops for managing nematodes. Plant parasitic nematodes play great roles both harmful and beneficial in agriculture. Both are important as their actions have economic propositions.

Population Dynamics—The Soil Biology

Since 1998-99 soil biology/biodynamics aspects of important plant parasitic nematodes have been studied under different prevailing wheat based cropping systems in details under AICW&BIP.

The cropping systems which were considered for this study were Rice-Wheat (at Ludhiana, Karnal, Delhi, Pusa-Bihar, and Faizabad), Cotton-Wheat (at Hisar and Ludhiana), Maize-Wheat (at Pusa-Bihar and Faizabad), Soybean-Wheat (at Ludhiana and Delhi), Groundnut-Wheat (at Durgapura and Anand), and Bajra-Wheat (at Durgapura and Anand) throughout the wheat growing zones of India. The findings revealed that *Tylenchorhynchus* and *Hoplolaimus* were present in all four cropping systems at Ludhiana. *Hirschmanniella* was present in rice under rice-wheat only whereas *Heterodera zeae* was present in maize under Maize-wheat system. Under Bajra-Wheat, *Tylenchorynchus* and *Hoplolaimus* increased when wheat was sown after Bajra. It was also recorded that under Bajra cysts of *Heterodera avenae* did not hatch.

At Karnal, R-W system as such had encouraged the growth of *Hoplolaimus* spp and *Tylenchorhynchus* spp in rice. *Hirshmanniella* was common in all the cropping system but its population was high during rice season.

In Himachal Pradesh, rice was affected by *Helicotylenchus diystera*, *Tylenchorhynchus nudus*, *Hirschmanniella gracilis*, *Pratylenchus zeae* and *Macoposthonia zenoplax* in order of dominance. *Hirschmanniella oryzae* was present in rice and *H. zeae* in maize. At Pusa, a steep decline in population of *Meloidogyne*, reniform nematode and lesion nematode were noticed but stunt, lance and spiral nematodes increased in wheat. In Haryana, *Hirschmanniella* and *Meloidogyne graminicola* were more in rice compared to wheat. The population of *Tylenchorhynchus* and *Helicotylenchus* have shown increasing trend in wheat and peak was achieved during January to March months. *Tylenchorhynchus* was higher during wheat season. In Soybean-Wheat population build up of all important nematodes was high. *Tylenchorhynchus* was high during maize as compared to wheat but population of *Hoplolaimus* was same during both the seasons. In Cotton-Wheat *Helicotylenchus*, *Hoplolaimus*, *Pratylenchus* and *Tylenchorhynchus* are the important ones. In Cotton-Wheat population of *Hoplolaimus* was maximum at cotton harvest whereas *Tylenchorhynchus* and *Helicotylenchus* were maximum during mid season of wheat at Hisar location. In Ludhiana, in cotton population of *Tylenchorhynchus* was very high (1600 nem/250 ml soil). Population of *Pratylenchus* spp got decreased in wheat in Groundnut-Wheat system but for *Tylenchorhynchus* it was reverse. Cysts of *Heterodera avenae* remained dormant and unhatched in groundnut.

Seed Gall Nematode—National Scenario

Ear cockle nematode, an important pest of wheat has potential to cause heavy losses in wheat. In the recent years, the disease has been reported to assume high incidence (1-10%) in some parts of the states like Bihar, Uttar Pradesh, and Madhya Pradesh (Vasudeva and Hingorani, 1952; Paruthi and Bhatti, 1985; Paruthi and Gupta, 1987; Nath and Pathak, 1993). The grain samples were obtained from mandies during the last six crop seasons to establish the severity and infestation so as to address trade related issues like sanitary, phytosanitary and market pathology. To address these issues a total of 21,907 grain samples were collected during the period 1998-99 to 2003-2004. In 1998-99, infestation with galls ranged between 0.01 to 50 per cent, in 1999-2000, between 0.01-0.35 per cent, in 2000-01 between 0.012-0.7 per cent, in 2001-02 between 0.05-1.6 per cent, during 2002-03 upto 0.24 per cent whereas in 2003-2004, it ranged between 0.05-8 per cent. Out of 7,140 samples analysed from Punjab none of the samples was found infested during last 3 crop seasons (2002, 2003 and 2004) indicating the areas to be disease free. In Haryana, 3 samples (2 from Gurgaon and 1 from Faridabad) were found infested during 2002-03. In the year 2003-04 grain infestation to the extent of 8 per cent was noticed at Jatmalpur in Darbhanga district of Bihar whereas at rest of the places in

Bihar it was upto 2.5 per cent, besides other places. Contrary to it, in 2003-2004 only 2 samples from Nuh and Palwal in Haryana contained infestation in the range of 0.05 per cent to 0.10 per cent. This indicates nematode is still prevalent in the zones. The recurrence of disease is due to seed contamination and the disease incidence depends upon the degree of admixture at the time of sowing. It can be effectively eradicated from the country by using clean seed obtained from seed certification agencies. Hence, seed industry can play a decisive role by developing entrepreneurship in providing gall free seed to the farmers to contain the disease.

Utilisation of Breeding Materials for Development of CCN Resistant Cultivar

Many developing countries unfortunately have limited resources and/or expertise to establish this information, and current control methods are based on the understanding the response of local cultivar to the pathogen. However, identification of consistent sources of resistance in wheat has not been possible in spite of the fact that thousands of genotypes have been screened in India alone (Dhawan and Nagesh, 1987). Therefore, there is need to search sources of resistance to this nematode among wild relatives of wheat. In order for cultivar resistance to be effective and desirable, a sufficient understanding of the number of species and pathotypes within species is essential. Although useful, a pathotype scheme for a species complex based on interaction with these cereal genera will not easily describe extensive variation in virulence. Furthermore, to date, these are few molecular or other diagnostic methods that can provide consistent and reliable pathotype and pathogenically differentiation. Any how, the traditional approach is still employed as being convenient and reliable.

Alternative Management of CCN

Earlier the use of soil fumigants like DD @ 300 litre/ha and DBCP @ 45 litre/ha were used. Later granular nematicides like Aldicarb 10G and Carbofuran 3G @ 1.5 kg ai/ha, respectively, were used which gave good protection of molya disease and also gave better plant growth and increased grain yield (Handa *et al.*, 1980; Mathur and Handa, 1984). Alternative to exclusive chemical management strategy of Molya disease (*Heterodera avenae*), concerted efforts were made by evaluating different organic, inorganic, resistant source and biological agents in combination during the wheat crop seasons of 1997-2005 (8 years) in order to keep cereal cyst nematode population below threshold level in endemic and hot spot areas. Though other treatments, like CCNRV-1, carbofuran in isolation reduced the number of cysts per plant but combination involving *Trichoderma* spp, FYM, and reduced amount of carbofuran proved better at Durgapura.

At Karnal, *Trichoderma viride* in combination with VAM fungi gave substantial growth and discouraged the cyst number to 5.40 per plant compared to 20.90 in check. When this exercise was repeated at Durgapura, *T. viride* + FYM + Carbofuran 3G @ 1.0 Kg ai/ha had yielded at par to that of carbofuran @ 1.5 Kg ai/ha in getting 40.76 q/ha and 41.94 q/ha yield and reduced the average number of cysts/plant upto 2.9 and 3.0 respectively, over the untreated control (yield - 24.24 q/ha and 18.5 cysts/plant). However, the treatment involving *T. viride* + FYM also gave significantly higher yield of 36.39 q/ha and reduced number of cysts/plant to 6.8 over 24.24 q/ha and 18.5 cysts/plant in control. At Hisar, all the treatments inhibited the nematode multiplication as compared to control but grain yield and shoot biomass increased in FYM @ 20 Tonnes/ha; Posse ST @ 0.75 Kg ai/ha + FYM @ 20 Tonnes/ha; seed treatment with *T. viride* + FYM @ 10 Tonnes/ha; seed treatment with *T. viride* + FYM @ 10 Tonnes/ha + Carbofuran 3G @ 0.75 ai/ha and seed treatment with *Gliocladium virens.* Carbofuran 3G @ 1.5 Kg ai/ha and seed treatment with *Trichoderma harzianum* increased yield but not biomass. At Karnal, among treatments, *T. viride* @ 4g/kg seed + Carbofuran 3G @ 1Kg ai/ha was the best after Carbofuran @ 1.5 Kg ai/ha. In subsequent year at Durgapura, the treatments of Carbofuran 3G @ 1.5 Kg ai/ha and compost + *T. viride* + half dose of Carbofuran 3G @ 0.75 Kg ai/ha gave the highest yield of 44.37 q/ha and 43.75 q/ha, respectively, and also reduced the cyst population significantly to 2.34 and 2.68 cysts/plant, respectively, over untreated control (yield 20.94 q/ha and 5.13 cysts/plant). Besides this, the treatment of compost + half dose Carbofuran, Neem Seed Powder and CCN resistant line (CCNRV-1) also gave significantly higher yield - 40.52. 38.02 and 40.83 q/ha and also reduced the average CCN count up to 2.73, 2.85, and 0.70, respectively, over untreated control (yield 20.94 q/ha and 5.13 cysts/plant). It was observed that *T. viride*, when used alone as seed treatment, did not produce significantly higher yield but gave slight reduction in the cyst counts. At Hisar, result showed that all the treatments except seed treatment with *Azotobacter chroococcum* @ 4 per cent proved effective in reducing the cyst population significantly as compared to control. Seed treatment either with *A. chroococcum* or *T. viride* along with soil application of carbofuran 3G @ 0.75 kg ai/ha was as effective as 1.5 kg ai/ha soil application of carbofuran 3G. These findings suggest that *T. viride* in combination with compost and half dose of carbofuran can reduce substantially the cyst population and improve the health of soil.

Wheat Seed Galls and Their Importance in Wheat Export

Wheat galls (the inciter of this disease is *Anguina tritici*, a nematode) though cause insignificant damage but in modern agriculture ability to export wheat grains in

international market is greatly hampered if historical records are available of the presence of this pathogen in the grain producing areas from where exports are to go. Here the SPS issues play deciding role. The major implications of the SPS Agreement are in the areas of developing pest risk analysis (PRA), fixing appropriate level of protection (ALP) and identifying nematode free areas. On contrary, generally more damage is experienced due to poor agricultural practices, monoculture and use of poor quality seed in third world countries. In some cases, combined infection of *Anguina tritict* and *Neovossia indica* in wheat seed galls were observed. Galls with both the fungus and nematode contained fewer nematodes than galls with only nematodes (Paruthi and Bhatti, 1980).

(a) Global prevalence of ECN: The countries namely, Australia, Afghanistan, Brazil, Bulgaria, China, Egypt, Ethiopia, Hungary, India, Iran, Iraq, Israel, Lithuania, New Zealand, Pakistan, Poland, Romania, Russia, Syria, Switzerland, Turkey, and Yugoslavia suffer from this wheat galls. It has been observed that nematode damage (wheat galls) is negligible in the countries adopting modern mechanical and cleaning procedures to separate the nematode galls from visible wheat seeds. The use of high quality seeds has nearly eradicated this nematode from developed countries. However, nematodes cause severe crop losses to rye (25-65%) and wheat (20-50%) in third world countries where poor agricultural practices monoculture, and the use of poor quality seed are widespread. The nematode is damaging pest in third world countries. It is a pest of regulatory significance in developed countries. Taking in to consideration the above version, large priority rating for a complete risk assessment and declaring gall free areas as per ISPM norms are required.

(b) Distribution: The occurrence of this disease is an indication of poor agriculture where seed is not replaced for years together. The disease is prevalent in Bihar, Uttar Pradesh, Rajasthan, Madhya Pradesh and Chattisgarh.

(c) Sporadic incidences, an example: In 1992, the Gaya, Patna, Nevada and Munger districts of Bihar got seriously affected by this disease. Darbhanga and Madhubani districts in Bihar experienced heavy damage owing to severe intensity of this disease in 1997. In the year 1999, village Paloi of Powai Tehsil in Panna district of Madhya Pradesh, suffered huge losses due to ear cockle disease. Chattarpur, Satna and Tikamgarh also got affected (Singh *et al.,* 2001).

(d) Present status in India: Not found in Punjab and Haryana but prevalent in Bihar, eastern parts of Uttar Pradesh, Rajasthan, Madhya Pradesh and Chattisgarh. It has been experienced that with the seed replacement this disease vanishes.

(e) Key host: Wheat including bread and durum, Emer, Rye, Barley and Triticale are hosts but Oat is not a host.

(f) Life cycle: Juveniles (J2) emerges from seed galls in soil and crawls on to the newly germinated seedlings. They (J2) establish infection sites between young leaves and feed as ectoparasites causing leaf crinkling and distortion to the plants. Later, they penetrate the flower buds at the time of flower bud initiation. J2 stimulates the formation of galls in floral tissues in place of seed development. Juvenile development is completely inside the galls. Newly formed females deposit eggs, which hatch producing J2, which remains encased in the galls in anhydrobiotic condition and perpetuate plant infection in following years. Dried cockles get harvested with fully developed healthy seeds. Each gall contains upto 12,000 J2 in it.

(g) Symptom of this disease: Initially diseased plants grow along soil surface (prostrate) and after few days, they take upright growth. Basal swelling appears in 20-25 days old seedlings. Crinkling, curling and twisting of leaves are invariably seen at seedling stage. Diseased plants stay dwarf and conspicuous patches can be noticed in affected fields. Diseased plants produce profuse non-productive tillers as well as small, broad, less owned or ownless earheads. These earheads remain green for long and produce nematode galls in place of grain. On harvesting and threshing, these galls fall in to the soil or get mixed up with healthy grains as harvest. If these grains are used as seed next year, the disease perpetuation and appearance take place. The ear cockle and tundu diseases depend on the presence of both the organisms and on temperature, humidity, age of seedlings and depth of placement of galls (Midha and Swarup, 1972). Karnal bunt has also been found to occur along with seed galls. Galls with both the fungus and nematode contained fewer nematodes than galls with only nematodes (Paruthi and Bhatti, 1980).

(h) International experience with seedgalls in wheat export: Brazil is one of the world's largest wheat importers. Brazil relies on imports for the majority of its wheat consumption with Argentina which supplies about 90 per cent of Brazil's import needs. Brazil once banned (blocked) US wheat on basis of presence of TCK smut, Cereal stripe and flag smut as well as seed galls. Importation of US wheat from the states of Washington, Oregon, Idaho, California, Nevada, and Arizona remained prohibited due to phytosanitary concerns. On March 15, 2001 Ministry of Agriculture, Brazil lifted ban on US soft wheat on the condition that exports of these wheat varieties must now come with additional declaration in the phytosanitary certificate that the wheat comes from an area free of *Anguina tritici*, and cannot be shipped out of west coast port. On contrary, Argentina enjoyed many advantages in the Brazilian market, such as proximity, lower

transportation cost, shorter delivery times and protection from the 10 per cent mercosul duty and 25 per cent merchant marine tax. So there were tug of wars among Brazil, Argentina and USA. Moreover, US wheat had an opportunity from May to September in Brazil as local harvest came after that.

The *Anguina tritici* do occur in Australia. Hundred years back economic problems due to this nematode were recorded in southern states like South Australia, Victoria, Tasmania, and Western Australia. Now it can be found only in small pockets of the western Australian belt particularly with short growing seasons, very dry summer and a tendency towards continuous wheat production. Crop rotation and seed cleaning has either eliminated the ECN incidence in other parts of Australia. Some markets in Middle East still require a shipment from Australia to be free of *Anguina tritici* because of perception of the effect on quality, and not for phytosanitary reasons. Though *A. tritici* is found in most of the Middle East countries, so without area freedom, this nematode could not be considered quarantine organism. *A. tritici* is easily controlled in modern agriculture and trade concerns are not phytosanitary in nature, whether it is appropriate that it be given a major quarantine pest. In US, 30 years ago this nematode was recorded. In February, 2003, though 18 countries passed regulations for this nematode that are phytosanitary in nature but still a question mark stands as to put this nematode under phytosanitary.

(i) Seed certification, as an alternative to pest free areas certification: Seed certification may serve as an alternative to pest free areas certification programme which would be easier to implement in this case compared to a pest free area certification programme in the cropping zone. TBT (Technical Barriers to Trade) is an agreement whereby certain conditions permit the denial of entry of imports based on non-phytosanitary issues such as quality of produce and packaging also. Though phytosanitary issues are related to the denial of entry based on presence of organisms/prohibited pests in the product of the exporting countries but TBT may also raise its head.

(j) Documents required: Supporting documents, other than phytosanitary certificates, are required in nowadays trade. Some importing countries may require other supporting documents other than phytosanitary certificate, for example a CITES certificate or a treatment certificate. The facilitators advise that the relevant standards, where necessary, should be followed. PRA is need of the situation and it has to be done. This abbreviation (EESEY) satisfies the requirement of PRA. The determination of the status of a quarantine pest may be summarised by the above alphabets - Entry,

Establishment, Spread, Economics and if pest is meeting all these requirements (Yes), then it can be categorised as quarantine pest.

(k) Prevent the disease through IPM approach: Use gall free seed or clean the gall infested seed lot. Certified seed obtained from reliable sources/agencies which are expected to be gall free, be employed. If farmers want to use their own seed (previous years harvest) they must ensure that there is no gall in the seed lot. Galls are smaller than the healthy grains and by sieving, they can be separated. In the light infestation (less than 2%), water floatation technique can be easily employed to remove galls from seed. Being lighter in weight, these galls float on the surface of water and can be easily separated. In case of severe infestation in seed lot, 2-5 per cent brine solution treatment can be used for gall separation. For this purpose, in 10 lit of water in a bucket, apply 200-500g of common salt (sodium chloride) and dissolve it. On stirring the seed in brine solution with wooden or iron stick, galls will float on the surface, collect them and finally burn them. Seed, thus obtained, should be washed 2-3 times in plain water and shade dry before sowing. The farmers may replace their seed with certified seeds of improved varieties of the area after every four to five years.

Conclusion

CCN has been an important nematode and various approaches as mentioned above have been effective in containing this nematode. In spite of best efforts in containing it, it has been observed that CCN is reappearing in erstwhile known areas and spreading in newer areas especially in the states of Rajasthan, Haryana and Punjab. In our country *Anguina* infested wheat galls are present but it is required that pest free areas be demarcated as per norms fixed by ISPM and other requisites so that whenever seed gall comes in the way of export, at least documents will be in position to support our version. In present day global trade, many petty issues become the deciding factors and influence the trade, hence preparedness to face those situation is highly required and desirable.

References

Dhawan, S.C. and Nagesh, M. (1987). "Tolerance in wheat against cereal cyst nematode, *Heterodera avenae." Indian J. Nematol.* **17**: 336-338.

Dhawan, S.C. and Pankaj (1998). "Nematode pests of wheat and barley." Pages 12-25 in *Nematode Diseases in Plants* (Trivedi, P.C., ed.), New Delhi, India: CBS Publishers and Distributors.

Handa, D.K.; Mathur, B.N.; Sharma, G.L.; and Yadav, B.D. (1980). *Indian Journal of Mycology and Plant Pathology.* **40** (2): VII.

Kaur, Damanjeet and Sharma, R.C. (2003). "Effect of seed replacement on the infestation of ear cockle nematode of wheat in Punjab." *Seed Research.* **31** (2): 228-233.

Mathur, B.N. and Handa, D.K. (1984). First Intl. Congress of Nematology, Guelph, Ontario, Canada, Aug. 5-10, pp. 62 (abstr.).

Midha, S.K. and Swarup, G. (1972). Factors affecting development of ear cockle and tundu diseases of wheat. **2**: 97-104.

Nath, R.P. and Pathak, K.N. (1993). "Widespread occurrence of ear cockle disease of wheat in Bihar." *Indian Journal of Nematology,* **23**: 124-130.

Paruthi, I.J. and Bhatti, D.S. (1980). "Concomitant occurrence of *Anguina tritici* and KB fungus *(Neovossia indica)* in wheat seed galls." *Indian Journal of Nematology,* **10**: (2) 256-257.

Paruthi, I.J. and Bhatti, D.S. (1985). "Estimation of loss in yield and incidence of *Anguina tritici." International Nematology Network Newsletter.* **2**: 13-16.

Paruthi, I.J. and Gupta, D.C. (1987). "Incidence of tundu in barley and kanki in wheat field infested with *Anguina tritici." Haryana Agricultural University Journal of Research.* **17**: 78-79.

Reports of the Co-ordinated Experiments, (1997-1998; 1998-99; 1999-2000; 2000-2001; 2001-2002; 2002-2003; 2003-2004; 2004-2005). Crop Protection Programme, AICW&BIP, Directorate of Wheat Research, Karnal.

Singh, A.K.; Sharma, A.K. and Nagarajan, S. (2000). Ear cockle disease of wheat-Management at ease. *Wheat Extension Bulletin*-**10**, Directorate of Wheat Research, Karnal-132 001.

"Twenty Years of Co-ordinated Wheat Research. 1961-1986." Editors: J.P. Tandon and A.P. Sethi, *Wheat Project Directorate, AICWIP,* IARI, New Delhi-12, pp. 189-206.

Vasudeva, R.S. and Hingorani, M.K. (1952). Bacterial disease of wheat caused by *Corynebacterium tritici* (Hutchinson) Bergey *et al., Phytopathology.* **42**: 291-293.

❑❑❑

Index