INTEGRATED MANAGEMENT OF ROOT-KNOT NEMATODE, *MELOIDOGYNE INCOGNITA* (KOFOID & WHITE) CHITWOOD IN COLEUS, *SOLENOSTEMON ROTUNDIFOLIUS* (POIR) MORTON

NISHA, M.S.

Thesis submitted in partial fulfilment of the requirement for the degree of

Doctor of Philosophy in Agriculture

Faculty of Agriculture
Kerala Agricultural University, Thrissur

2005

Department of Agricultural Entomology
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM-695 522

Dedicated to

My Achan, Amma &

Brother

DECLARATION

I hereby declare that this thesis entitled '**Integrated management of root-knot nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood in coleus, *Solenostemon rotundifolius* (Poir) Morton**' is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

Vellayani,
27-05-2005.

NISHA, M.S.
(2002-21-02)

CERTIFICATE

Certified that this thesis entitled '**Integrated management of root-knot nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood in coleus, *Solenostemon rotundifolius* (Poir) Morton**' is a record of research work done independently by Nisha, M.S. (2002-21-02) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Vellayani,
27-05-2005.

Dr. M.S. SHEELA
(Chairperson, Advisory Committee)
Associate Professor,
Department of Agricultural Entomology,
College of Agriculture, Vellayani,
Thiruvananthapuram-695 522.

Approved by

Chairperson :

Dr. M.S. SHEELA
Associate Professor,
Department of Agricultural Entomology,
College of Agriculture, Vellayani,
Thiruvananthapuram - 695 522.

12.7.05

Members:

Dr. T. NALINAKUMARI,
Associate Professor and Head,
Department of Agricultural Entomology,
College of Agriculture, Vellayani,
Thiruvananthapuram- 695 522.

13.7.05

Dr. C. NANDAKUMAR,
Associate Professor,
Department of Agricultural Entomology,
College of Agriculture, Vellayani,
Thiruvananthapuram - 695 522.

13.7.05

Dr. C. GOKULAPALAN,
Associate Professor,
Department of Plant Pathology,
College of Agriculture, Vellayani,
Thiruvananthapuram – 695522.

13/7/05

Dr. VIJAYARAGHAVAKUMAR
Associate Professor,
Department of Agricultural Statistics,
College of Agriculture, Vellayani
Thiruvananthapuram-695522.

13/07/05

External Examiner :

Dr. M. Sivakumar, Ph.D.,
Professor, Department of Nematology
Tamil Nadu Agricultural University
Coimbatore – 641 003.

13.7.05

ACKNOWLEDGEMENT

With immense pleasure and gratitude, I express my deep indebtedness to Dr. M.S. Sheela, Associate Professor of Agricultural Entomology and Chairperson of Advisory Committee for her valuable and masterly guidance, critical supervision and inspiring suggestions throughout the course of investigation and preparation of the thesis. Inspite of her busy schedule she managed to suggest suitable ideas and was always responsive to clear the bottlenecks encountered during the thesis work. Her inspiring words, wholehearted technical and emotional help and unfailing support at critical stages have made this attempt a reality. Words fail to express my deep and sincere obligation for the sincerity, wholehearted co-operation and blessings shown by her during the entire course of study. I wish to give my utmost respect to her dedication in research and teaching.

I am extremely grateful to Dr. T. Nalinakumari, Associate Professor and Head, Department of Agricultural Entomology for her timely advice, constructive criticism, keen interest, constant encouragement and overwhelming support extended throughout the study.

I extent my deep sense of immense gratitude and admiration to Dr. C. Nandakumar, Associate Professor, Department of Agricultural Entomology for his valuable comments, helpful suggestions, inspiring guidance, sustained interest, unstinted support and ever willing help for the critical scrutiny of the manuscript.

My sincere thanks and gratitude to Dr. C. Gokulapalan, Associate Professor, Department of Plant Pathology for his valuable ever willing help, pertinent suggestions and continued inspiration throughout the period of investigation and preparation of thesis.

I wish to express my heartfelt gratitude and indebtedness to Dr. Vijayaraghavakumar, Associate Professor, Department of Agricultural Statistics for his advice and help rendered in the statistical analysis of the data, subsequent interpretation, valuable suggestions and critical scrutiny of the manuscript.

My sincere thanks and gratitude to Dr. C. Mohandas, Principal Scientist, CTCRI, Dr. Umamaheswaran, Dr. A. Naseema, Dr. Hebsybai, Dr. Arthur Jacob, Dr. Naseema Beevi, Dr. M.H. Faizal, Dr. N. Anitha, Dr. K.D. Prathapan, Dr. K. Sudharma, Dr. Thomas Biju Mathew, Dr. S. Devanesan, Dr. Jiji, T., Dr. K.S. Premila, Dr. Krishnakumar, the teaching and non-teaching staff of Department of Agricultural Entomology and Agronomy for their sincere co-operation and assistance during the course of study.

I am grateful to Sri. C.E. Ajithkumar, Junior Programmer, Agricultural Statistics for analyzing the experimental data.

I wish to express my obligation to Sri. Manoj S. and Dr. C. Gokulapalan for the help in taking photographs.

I express my deepest sense of gratitude and indebtedness to Geetha, G. Nath, Jayaraj, Honey, Ramjitha, Asha and Geeji for their moral support, constant encouragement and sincere everwilling help which is always unforgettable.

I am thankful to my friends Priya, Poornima, Ambily, Archana, Heera, Nandini, Smitha, Heera, Manu, Rehna, Roshna, Sheena, Lekha, Yasin, Rini, Deepu, Ajith, Jayesh, Tamilvel, Santhosh, Sarath, Sumesh, Hanesh, Manu P. Many and Kishore who were of great help at times of need.

My heartfelt thanks to Biju, ARDRA for the patience, typing the manuscript within a short period with utmost care and being a good understanding friend.

I am grateful to National Agricultural Technology Project (NATP), our beloved former Dean, Dr. G. Sreekantan Nair, my guide Sheela teacher and Kerala Agricultural University for granting me the Senior Research Fellowship and other necessary facilities for the conduct of research.

I take this occasion to dedicate this thesis to my parents, brother and ammamma who are solely responsible for all I have achieved in life and to acknowledge their utmost affection, inspiration and prayers which enabled me to complete the work in time.

Above all, I bow my head before the eternal God Almighty for the bountiful blessings showered upon me to complete the work successfully.

Nisha M.S.

CONTENTS

LIST OF TABLES

LIST OF TABLES CONTINUED

LIST OF TABLES CONTINUED

LIST OF TABLES CONTINUED

LIST OF PLATES

LIST OF FIGURES

Introduction

1. INTRODUCTION

Indian agriculture is currently going through a competitive phase for sustainability and profitability. With the World Trade Organization demands looming large on the face of stakeholders involved in research on agriculture there is an enormous amount of pressure for sustainable pest management through the use of ecofriendly approaches. Biorationals like the microbial organisms are known to possess great potential for the management of pests, diseases and nematodes. Recently the importance of biointensive integrated pest management in combination with resistant varieties has been recognized and several groups working on this aspect have mushroomed in various institutions all over India. In spite of all these efforts, practical biointensive integrated management strategies for different crops are lacking especially for root and tuber crops.

Root and tuber crops are among the world's most important food crops, with a great potential to improve food security, eradicate starvation and alleviate poverty in resource poor countries. For many farmers, these crops are not only their staple food but also their principal source of income because of the growing demand of tubers in urban areas. Koorka or coleus, *Solenostemon rotundifolius* (Poir) Morton is a short duration under exploited tuber yielding vegetable, mainly cultivated in the northern districts of Kerala. Of late, the demand for tubers has fuelled the cultivation in the southern districts also. The coleus tubers are rich in carbohydrates (18 - 21 per cent), minerals like calcium and iron, vitamins like thiamine, riboflavin, niacin and ascorbic acid.

One of the major constraints in production of tubers is the losses sustained due to attack by insects, diseases and nematodes. Nematodes represent a unique challenge to agricultural research, in that they combine the potential for serious reductions in growth and yield in a wide range of

crop plants, often with rather non-specific and easily misdiagnosed symptoms. Sathyarajan *et al.* (1966) reported root-knot nematode, *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949 infestation in *S. rotundifolius* from Kerala. Due to the attack of *M. incognita* in *S. rotundifolius* conspicuous gall like swellings are formed in the roots resulting in malformation of tubers, unfit for immediate consumption as well as for storage. Coleus being a tuber crop, attack by soil inhabiting nematodes occur in the roots and tubers in the soil. The nematodes continue to multiply inside the tuber after harvest during transportation and storage. The quantity and quality of the produce also get deteriorated. The crop loss due to *M. incognita* was 92 per cent (in terms of fresh weight of tubers) at an inoculum level of 10,000 *M. incognita* larvae per pot (Sosamma, 1988).

Development of the concept of pest management and their implementation have led to a greater appreciation of the need for a wide range of tactics for nematode control. Sole reliance on pesticides is not sustainable because of the associated problems of environmental degradation and secondary outbreak due to elimination of natural enemies. Other effective and environment friendly methods have to be adopted and this trend has gained momentum in recent years. One among them is the use of microbial pesticides. When used as part of IPM programmes, microbial pesticides (bacteria, fungi, nematodes, protozoans and viruses) are viable, safer and ecofriendly alternatives. Since coleus is a short duration crop and tubers are the consumable part, the application of chemical pesticides in soil will adversely affect soil microflora and fauna resulting in very high level of pesticide residues in harvested produce. By developing suitable biointensive integrated management strategy using combinations of techniques and practices giving emphasis to biocontrol agents and other non-chemical measures, the *M. incognita* population can be maintained below the threshold levels and the over dependence on

pesticides can be avoided. In this context, the present study was undertaken with the following objectives.

1) To assess crop loss in *S. rotundifolius* due to *M. incognita* under micro plots as well as storage condition for evaluating the damage potential.
2) To study the viability of nematode infested tubers on storage.
3) To estimate the biochemical changes due to *M. incognita* infestation.
4) Screening of varieties/lines/accessions against *M. incognita* to select a suitable resistant one.
5) Management studies under nursery condition using physical methods, bioagents and organic amendment in comparison with the chemical.
6) Management studies under main field condition using bioagents and organic amendments singly and in combinations in comparison with the chemical.
7) To evolve an integrated management strategy using selected treatments from nursery and main field along with selected resistant variety.

Review of Literature

2. REVIEW OF LITERATURE

Literature pertaining to the crop loss and biochemical changes caused by root-knot nematode, *Meloidogyne incognita* (Kofoid and White) Chitwood in coleus, *Solenostemon rotundifolius* (Poir) Morton are presented here. The literature on varietal resistance, management in nursery, main field and the integrated strategy are also included.

2.1 CROP LOSS

The damage potential, density and distribution of plant parasitic nematodes in an area adversely affects the growth, vigour and yield of the crops grown. The retrievable yield loss due to important nematode pests in the field as well as storage in various crops is being reviewed.

2.1.1 Pot Culture Condition

Sathyarajan *et al.* (1966) reported root-knot nematode infestation in coleus from Kerala. The market value of yam was reduced by 40 per cent due to root-knot nematode infestation (Atu *et al.*, 1983). Patnaik and Das (1986) observed significant reduction in coleus tuber yield with 100 nematodes per pot onwards. The crop loss due to root-knot nematode was 92 per cent (in terms of fresh weight of tubers) at an inoculum level of 10,000 *M. incognita* larvae per pot (Sosamma, 1988). In potato, *M. incognita* population density @ one J_2 per g of soil was considered as the damage threshold level (Nagesh, 1996). Mohandas and Ramakrishnan (1997) reported that an initial inoculum level of 100 juveniles of *M. incognita* per plant caused significant reduction in fresh and dry fibrous root weight and tuber yield of *Dioscorea rotundata* Poir.

2.1.2 Field Condition

2.1.2.1 Vegetables

Bhatti and Jain (1977) reported that the losses in yield of okra, tomato and brinjal were 90.90, 46.20 and 27.30 per cent respectively in

field infested with *M. incognita* @ 2800-3460 larvae per kg soil. The yield loss due to *M. incognita* varied from 28.00 to 43.00 per cent among various crops *viz.*, *Solanum melongena* (L.), *Abelmoschus esculentus* L. Moench, *Phaseolus vulgaris* (L.) and *Vigna unguiculata* (L.) (Reddy, 1986). Subramaniyan *et al.* (1990) reported an yield loss of 42.05 to 54.42 per cent due to *M. incognita* in tomato.

2.1.2.2 Pulses

French bean plants infested with *M. incognita* showed reduction in chlorophyll content, plant dry weight, number of buds, flowers, pods and seeds (Malakeberhan *et al.*, 1986). In a soybean field heavily infested with *M. incognita*, yield was reduced by 55.60 per cent and 100 seed weight by 33.60 per cent (Antonio, 1988). *M. incognita* caused 12.70 and 12.30 per cent yield loss in greengram and cowpea respectively (Patel *et al.*, 1993). Root-knot nematode, *Meloidogyne javanica* (Treub, 1885) Chitwood, 1949 had resulted in a loss to the tune of 23.00 per cent in grain yield of urd bean (Ali, 1995).

2.1.2.3 Spices

In ginger, the reduction in rhizome weight varied from 9.40 to 46.40 per cent as the inoculum level increased from 10 to 5000 (Charles, 1978). Patel *et al.* (1981) reported heavy galling of roots and reduced size of rhizomes in turmeric infested with *M. incognita*. In turmeric statistically significant yield reduction occurred at an inoculum level of 100 J_2 per plant (Haider *et al.*, 1988). Eapen (1994) reported 46.10 per cent yield loss in small cardamom at four nematodes 100 cm^{-3} soil. An yield loss of 20.00 per cent in ginger due to *M. incognita* with an initial population level of 200 larvae per 200 cc of soil (Makhnotra and Khan, 1997).

2.1.2.4 Medicinal Plants

Under field condition, *M. incognita* caused 47.00 and 86.70 per cent reduction in top weight and shade dried leaf yield of Patchouli, *Pogostemon cablin* (Blanco) Benth. at 10,000 J_2 level per plant respectively (Prasad and Reddy, 1984). Nalinakumari *et al.* (1995) reported 56.90 and 67.70 per cent reduction of chewable leaves of betel vine at an initial inoculum level of 4000 and 5000 *M. incognita* larvae per plant. The biometric characters and yield of *Ocimum sanctum* L. was significantly reduced by *M. incognita* compared to uninoculated plants and thus reduction was in accordance with the initial inoculum levels (Haseeb *et al.*, 1999).

2.1.2.5 Others

Meloidogyne spp. had incurred 32.66 per cent yield loss in tobacco in Pinardel Rio Province, Cuba (Garcia and Espinosa, 1982). Saikia and Phukan (1986) reported 57.00 to 68.00 and 49.30 to 51.90 per cent reduction in fresh and dry weights of shoots as well as fibre yield respectively in jute in two subsequent years. There was a loss of 0.35 per cent in fruit yield (0.811 g) per tree for every one nematode increase per 5 g root due to *M. incognita* infestation in papaya (Ramakrishnan and Rajendran, 1998).

2.1.3 Avoidable Yield Loss

2.1.3.1 Tubers

Pillai (1976) reported an avoidable yield loss of 53.00 and 47.00 per cent in coleus by the application of Nemagon and Terracur respectively. In red beet, *Beta vulgaris* L. var. *Crassa*. Fifty nematodes per kg soil caused significant decrease in fresh (14.62 per cent) and dry (21.60 per cent) root weight (Pathak and Keshari, 2000).

2.1.3.2 Vegetables

In brinjal, an initial population of 248 *M. incognita* larvae per 250 g soil resulted in an avoidable loss of 20 and 22 per cent in weight and number of fruits respectively (KAU, 1993). Avoidable yield loss to the extent of 71.90 per cent due to *M. incognita* and 47.30 per cent due to *M. javanica* have been reported in tomato by Jain *et al.* (1994). Jain *et al.* (1997) reported that avoidable yield losses in tomato was 19.30 per cent using infected seedlings, but was 0.70 and 0.30 per cent when using non infected and resistant variety respectively. An avoidable yield loss of 21.58 per cent at an initial inoculum level of 340 juveniles per 250 cc by the application of carbofuran three kg a.i. ha^{-1} in okra (Deka and Phukan, 1997). In green chillies, spot application of carbofuran and phorate into the soil @ two kg ha^{-1} resulted in an avoidable yield loss of 53.36 and 39.76 per cent respectively (Yadav and Mathur, 1999).

2.1.3.3 Spices

In turmeric, an avoidable yield loss of 45 per cent was observed due to *M. incognita* infestation (Hebsybai *et al.*, 1995). The avoidable yield loss due to *M. incognita* in ginger was 43.00 per cent at an initial population level of 166 juveniles per 250 g soil sample (Sheela *et al.*, 1995).

2.1.3.4 Medicinal Plants

Hazarika *et al.* (1999) reported an avoidable yield loss of 17.95 (number of leaves / vine) and 29.06 (fresh weight of leaves) per cent in betelvine. An avoidable yield loss of 43.96 and 36.00 per cent of 1000 and 100 J_2 level of *M. incognita* respectively in *Plumbago rosea* L. (Kumar, 2004).

2.1.3.5 Others

An avoidable yield loss of 16.44 per cent was obtained in sunflower by the application of carbofuran two kg a.i. ha^{-1} (Devappa *et al.*, 1998).

Application of carbofuran and phenamiphos @ two kg ha^{-1} a day or two prior to seeding resulted in a loss of 12.90 and 17.20 per cent respectively in transplantable papaya seedlings (Patel *et al.*, 2000). The avoidable loss in banana cv. Poovan due to *M. incognita* was 30.90 per cent using carbofuran @ four kg a.i. ha^{-1} (Jonathan and Rajendran, 2000a)

2.1.4 Storage

Mohandas and Ramakrishnan (1998) reported that coleus tubers heavily infested with root-knot nematode started rotting, while less infested tubers shrunk and developed more prominent galls during storage. The heavily infested tubers suffered rapid weight loss compared to healthy and less infested tubers.

2.1.4.1 Germination and Growth Characters

Singh (1977) reported that in cauliflower, brinjal and tomato seed germination and seedling emergence were inversely correlated with the increase in *M. incognita* population. Significant reduction in germination of greengram seeds (Prasad, 1981) and red beet seeds (Keshari and Pathak, 2000) was recorded at 500 nematodes per kg soil. There was no report on the effect of *M. incognita* on the germination and growth characters of tuber crops.

2.2 BIOCHEMICAL CHANGES

2.2.1 Protein

Increased protein synthesis in hypersensitive cells of tomato galls as a result of *M. incognita* infestation was reported by Paulson and Webster (1972). Similar results reported in tomato varieties Pusa Ruby, SL-120 and Nematex by Ganguly and Dasgupta (1981).

In brinjal, increase in total protein and amino acid content in roots infested with *M. incognita* was reported by Singh *et al.* (1978). However, Tayal and Agarwal (1982) reported increased level of soluble proteins and amino acids in *M. incognita* infested tissues of brinjal seedlings.

Increased accumulation of protein was observed in carrot (resistant cv. Black) galls as a result of *M. incognita* infestation (Arya and Tiagi, 1982).

Basu and Sukul (1983) reported that in okra, the *M. incognita* inoculated plants had higher level of protein but lower levels of carbohydrates and lipids in roots than the uninoculated ones.

Singh *et al.* (1984) reported increased level of protein in cowpea infested with *M. incognita*. Ganguly *et al.* (1991) also reported considerable increase of total soluble protein in cowpea cv. Pusa Do Fasli by root-knot nematode, *M. incognita* race-1. Sirohi and Dasgupta (1993) obtained elevated levels of protein in resistant cowpea cv. C-152 than in susceptible cultivar Pusa Do Fasli inoculated with *M. incognita*. In chickpea, as a result of *M. javanica* infestation, the protein content increased from 10.64 to 17.02 and 14.59 to 17.90 per cent in root and stem respectively (Upadhyay and Banerjee, 1986). Simte and Dasgupta (1987) observed higher concentration of total proteins in soybean roots inoculated with *M. incognita*.

Parihar *et al.* (1995) reported increase in total protein content in infected tissues as compared to healthy ones suggesting a high rate of metabolism triggered by pathogenesis leading to more enzyme production in maize tissues infected with corn cyst nematode, *Heterodera zeae* Koshy.

2.2.2 Sugar

Singh *et al.* (1978) reported a decrease in total sugars in roots of brinjal infested with *M. incognita*. However, a reduction of 23 per cent in total sugar content of brinjal seedlings variety Pusa Purple Long by *M. incognita* infestation was reported by Tayal and Agarwal (1982). Rashid *et al.* (1985) reported a decrease in sugar concentration (from 441 to 378 μ mol glucose g^{-1} tissue) in diseased seedlings of sugar beet cv.

Ramonskaya inoculated with 15,000 freshly hatched J_2 of *M. incognita*. In chickpea plants as a result of *M. javanica* infection the sugar content showed a decreasing trend from 7.27 to 13.06 and 9.27 to 32.22 per cent in the root and stem respectively (Upadhyay and Banerjee, 1986).

2.2.3 Starch

Tayal and Agarwal (1982) reported 59.34 per cent reduction in starch content in brinjal seedling variety Pusa Purple Long infected with *M. incognita*. The percentage of starch on fresh weight basis showed two per cent reduction in infested coleus compared to 16.00 per cent in control (Mohandas *et al.*, 1988).

2.2.4 Crude Fibre

Naidu *et al.* (2000) reported 21.30 per cent reduction in crude fibre content of groundnut seeds of nematode disease resistant variety TPT-3 due to *Tylenchorhynchus brevilineatus* Williams, 1960 infestation.

2.3 VARIETAL RESISTANCE

Resistant varieties offer the cheapest and most convenient method of pest management. There was no report on resistance of root-knot nematode, *M. incognita* against coleus varieties/lines. Literature, pertaining to resistance of varieties against *M. incognita* to some related vegetable crops was reviewed and presented here.

2.3.1 Carrot and White Yam

Arya and Tiagi (1982) reported that among three carrot cultivars cv. Black was moderately resistant to *M. incognita* with root-knot index of 1.5. Out of 33 accessions of *D. rotundata*, five accessions *viz.*, Dr 22, 48, 167, 218 and 237 were found immune and nine accessions *viz.*, Dr 32, 36, 38, 41, 67, 74, 93, 305 and 345 were resistant to root-knot nematode (Mohandas *et al.*, 1998).

2.3.2 Ginger and Turmeric

Out of 48 accessions of turmeric and 116 accessions of ginger, seven turmeric and six ginger accessions were found to be resistant to root-knot nematode, *M. incognita*. Among these, one ginger and two turmeric accessions were highly resistant to root-knot nematode (Eapen *et al.*, 1998).

2.3.3 Brinjal

In brinjal, out of sixty nine cultivars / lines screened, cultivar Gulla was found highly resistant to *M. incognita*, race-1 and 2 (Ravichandra *et al.*, 1988). Ibrahim *et al.* (1998) found that egg plant cultivars Black Beauty, Black Long and White Long were highly susceptible to *Meloidogyne arenaria* (Neal, 1889) Chitwood, 1949. Aubergine lines Annamalai, KS-224, Vijay and 71-19 were resistant to *M. incognita* race-2. Azad Kranti, Arka Kusumkar, Banaras Giant, Rajendra Annapurna, Rajendra Baigan-II, Pant Rituraj, KS-223, M-53A, 71-14, 71-24, 72-12, 74-1, 74-8, 80-2, 80-13, 82-8, 83-4, 83-5 and 88-26 were moderately resistant (Haider *et al.*, 2001).

2.3.4 Tomato

Nadpuri *et al.* (1988) reported that the tomato variety, Punjab NR-7 showed resistance to root-knot nematode. Out of eight germplasm lines of tomato screened against *M. incognita* none were immune, but Selection-15 was resistant (Shelke *et al.*, 1995). BT-1, BT-3, BT-10, BT-12 and T-14 varieties of tomato exhibited moderate resistance to *M. incognita* (Nayak, 1995). Tomato cv. 88572 was found resistant to *M. incognita* (Shahzad *et al.*, 1999). Mahajan and Singh (2001) reported that out of one hundred and seventy eight lines or cultivars of tomato screened, cultivars VFN-8, Patriot, PAU-14, Punjab NR-7, Healani, 8-2-1-2-5, Nemadora and 1-6-1-4 were categorized as highly resistant to *M. incognita*, while 5-5-R, CXP-142, Spectrum and EC 1191994 were considered resistant. Out of 21 tomato cultivars, 11 cultivars (PAU-1, PAU-2, PNR-7, BT-1, IHR-864,

Ronita, SL-120, NTDR-1, Karnataka hybrid, 8-2-1-2-5 and 1-6-1-4) were resistant and two (PAU-4 and 7-3-1-4) were moderately resistant (Bhargava and Sharma, 2001). Among 34 tomato cultivars, CLN 1464A, CLN 977A, COFLCR-5, COMLCR-3 and Sunbelt were the resistant cultivars with root-knot indices of 1.50, 1.10, 2.20, 1.90 and 1.00 respectively (Mahajan, 2002). Among eight tomato cultivars, moderately resistant cultivars *viz.*, Vivek and Radha recorded maximum concentration of phenols, proteins, peroxidase and polyphenol oxidase enzymes conferring resistance to root-knot nematode (Gopinatha *et al.*, 2002a). Out of 47 germplasm lines of tomato, eight *viz.*, 8307, 8308, 8202, 8301, 1098, 8785, 6802 and 7014 were found highly resistant as they were free from gall formation, six germplasm lines (6536, 6404, 5902, 7006, 8713 and 4609) as resistant having root gall index of two whereas 8725, KS 176, 6512 and 6806 were moderately resistant with root gall index three (Kamalwanshi *et al.*, 2004). Among 132 varieties of tomato screened against *M. incognita* race-1, none were immune to *M. incognita* infection, whereas two lines (7418, 130053) were resistant and two (126004 and 378682) exhibited moderately resistant reaction (Sharma *et al.*, 2004).

2.3.5 Chilli

In chilli, among 31 cultivars tested against *M. incognita*, Malagachi yellow 12-3-3, Talandhari and Lacchi-2 were resistant whereas 10 cultivars were moderately resistant (Kaur and Mahajan, 1990). Mandore local 1 and 2 were assessed as moderately resistant to *M. incognita* (Pandey and Trivedi, 1990). Jwala was found resistant to races 1, 2 and 4 of *M. incognita* and immune to race 3, Suryamukhi green and chilli PC-1 were susceptible to *M. javanica* (Khan and Khan, 1991). Out of the 79 genotypes of *Capsicum annuum* Linn. screened for their reaction to *M. incognita* only K-2 was resistant whereas 14 genotypes were moderately resistant (Yadav and Mathur, 1993). The chilli cultivars Ch-19, Ch-21 and LCH-206 were found to be moderately resistant to

M. incognita (Sharma *et al.*, 1994). Among the six chilli cultivars, Khandri was found to be highly resistant to *M. javanica* (Hussain *et al.*, 1998). Out of the 38 chilli cultivars screened for nematode resistance, five cultivars (LPG 181, LPG 18-3, LPG 18-9, LPG 18-11 and NIC-23911) were resistant and 15 were moderately resistant (Bhargava and Sharma, 2001). Sundaram (2001) reported that out of fifty seven chilli genotypes, nine genotypes *viz.*, AC 52, AC 96, AC 110, AC 376, AC 548, AC 550, AC 568, AC 162 and AC 1824 were found resistant to *M. incognita*. The chilli cultivars J-218 and Ruby King were resistant to all races of *M. incognita* (Khan *et al.*, 2002). Out of seventeen chilli varieties/lines screened against *M. incognita*, BC 40-2, Utkal Abha, Utkal Rashmi and Pusa Jwala were found resistant. Varieties BC 40-1, BC-28, BC-24, BC-30, Utkal Ragini, G-2, G-4, Pusa Sadabhar, B.R. Red, Agnirekha, Lamx-235 and Berhampur Local were moderately resistant (Patnaik *et al*, 2004).

2.3.6 Onion

Among three varieties of Bellari onion *viz.*, Arka Kalyan, Arka Niketan and Arka Pragati screened against three species of root-knot nematodes *viz.*, *M. incognita*, *M. javanica* and *M. arenaria,* Arka Kalyan proved to be the most susceptible variety to the three nematode species (Sundarababu and Vadivelu, 1990).

2.3.7 Amaranthus

Mohanty and Das (1988) found that among thirteen amaranthus varieties screened against root-knot nematode, Bhuvaneswar local and Khantei Khanda exhibited resistance reaction.

2.3.8 Cucumber

Out of six cucumber cultivars tested against *M. incognita*, Poin sette was moderately resistant (Bharali and Phukan, 1996). Among seven gherkin cultivars screened against root-knot nematode, cultivar

PS 64487 showed significant increase in plant growth parameters and reduction in development and reproduction of root-knot nematode (Praveen and Gowda, 2004).

2.3.9 Pea / Cowpea / French bean

Out of the 30 cultivars / accessions of pea tested against *M. incognita* HFP-8909 and KFPD-27 were highly resistant while HFP-8913 was resistant (Praveen *et al.*, 1995). Kalita *et al.* (1999) reported that among 80 cowpea cultivars tested against *M. incognita*, IC 20695 and EC 43487 were resistant, 10 were moderately resistant and rest were susceptible. Among the 20 cultivars of *Vigna radiata* L., none of the cultivar was found resistant to *M. incognita*. HUM-11 was moderately resistant (Haseeb and Shukla, 2001). In *P. vulgaris,* among twelve varieties screened against *M. incognita,* none was found resistant (Dutta and Haider, 2001).

2.3.10 Chickpea

Jain and Trivedi (2000) reported that among 47 chickpea accessions evaluated for their reaction to *M. incognita*, variety RSG 617 was the least susceptible showing the least number of galls, eggs per egg mass, final nematode population and highest root/shoot length and weights. Among ten cultivars of chickpea cv. BG 1067 was categorized as tolerant one with increased peroxidase activity (33.40 per cent) (Chakrabarti and Mishra, 2002).

2.5 MANAGEMENT

2.5.1 Nursery Treatment

2.5.1.1 Soil Solarization in the Nursery

Soil solarization is a method of hydrothermal disinfection. The effect of solarization in the management of *M. incognita* in the nursery was investigated and the relevant literature pertaining to solarization has been reviewed and presented here.

Tomato

According to Jain and Gupta (1997a), polythene mulching significantly reduced the population of *M. javanica* in tomato nursery beds. Solarization at 44°C at 10 cm soil depth resulted cent per cent control of *M. incognita* in tomato nursery (Herrera *et al.*, 1999). Reddy *et al.* (2001) reported that soil solarization with clear transparent sheet for six weeks during hot summer showed an increase in soil temperature (8°C) resulting in significant reduction in population density of *M. incognita* (85.80 per cent) and *Pythium aphanidermatum* (Edson) Fitz. (85.40 per cent) in tomato. Soil solarization using 100 guage LLDPE clear polythene sheet for 15 days was very effective in reducing the nematode population in tomato nursery (35 per cent). Planting of tomato seedlings from solarized plots increased the yield to the tune of 58.00 per cent (Mahapatra and Mohanty, 2000).

Coffee

Cuadra *et al.* (1999) reported that soil solarization reduced the number of *M. incognita* race-2 and other nematodes in coffee nurseries during January to February and August to September.

Brinjal

Kamra and Gaur (1993) reported that in egg plant seedlings, root galling by *M. incognita* was decreased by 66.70 per cent and fresh weight of seedlings increased by 96.70 per cent with solarization.

Tobacco

Patel *et al.* (1995) reported that in tobacco nursery soil solarization using clear LDPE plastic of 100 guage for 15 days increased the soil temperature in the range of 38.10 to 53.80°C as against 33.40 to 50°C in control beds. This ultimately reduced the population of root-knot, stunt and reniform nematodes at seeding, root-knot index and increased the fresh weight of seedlings, number of transplantable and total seedlings.

Soil solarization of tobacco nursery beds using clear LDPE plastic during summer increased soil temperature by 9.5, 8.4 and 4.9°C at five, 10 and 15 cm soil depths respectively over non-solarized (Patel and Patel, 1998). Soil solarization with LDPE guage significantly reduced root-knot infection in FCV tobacco nursery and increased the height of tobacco transplants (Hussaini *et al.*, 2001).

2.5.1.2 Soil Solarizaiton in the Main Field

Ginger

Soil solarization after irrigation, 45 days prior to planting reduced soil microbial population and bacterial wilt disease in ginger. The maximum mean difference in temperature taken at 14.00 hour was 12.2°C in plots mulched after irrigation (Anith *et al.*, 2000).

Greengram

Jhala and Patel (2004) reported that soil solarization using 25 μ 100 LLPDE white plastic film for 15 days was effective against root-knot nematode with a higher yield of greengram.

Betel vine

Due to adoption of soil solarization, the soil temperature was increased from 51.10 to 61.90°C with a consequent reduction of 43.80 and 24.30 per cent in population of *Rotylenchulus reniformis* Linford and Oliveira, 1940 and *Helicotylenchus indicus* Siddiqui, 1963 respectively in betel vine gardens (Rao *et al.*, 1995).

2.5.2 Bioagents

Among the non chemical methods of controlling nematodes, use of biological control agents is of utmost importance. The relevant literature on important bioagents have been reviewed and presented.

2.5.2.1 Fungi

2.5.2.1.1 *Paecilomyces lilacinus*

The action of fungal parasites of eggs like *P. lilacinus* in reducing nematode population is a promising form of crop protection against *Meloidogyne* spp. and has now been recognized as a potential biocontrol agent of eggs of heteroid nematodes and those which deposits eggs in gelatinous matrix.

2.5.2.1.1.1 Effect on *M. incognita*

Tuber crops

P. lilacinus has been successfully used to manage root-knot nematode in potato (Jatala *et al.*, 1980) and carrot (Sivakumar, 1998).

Vegetables

Brinjal

P. lilacinus increased growth of brinjal plants and reduced root galling, egg masses and number of eggs per egg mass of *M. incognita* (Sharma and Trivedi, 1989). Root dip treatment of egg plant seedlings in formulation of *P. lilacinus* resulted in drastic reduction of *M. incognita* population (Rao *et al.*, 1998a). Khanna (2000) reported that an inoculum level of 3.6 g fungus per 600 g soil was the optimum level for keeping the root-knot nematode under check and enhancing the growth of brinjal plants. Application of *P. lilacinus* @ 10 g per pot improved the plant growth (length and weight of shoot and root) of brinjal and tomato by reducing the multiplication of *M. incognita* (Verma *et al.*, 2004).

Okra

P. lilacinus at an inoculum level of four g fungus culture (on rice grain medium) per kg soil reduced *M. incognita* attack in okra (Saikia and Roy, 1994).

Tomato

Khan and Saxena (1995) reported that *P. lilacinus* application reduced multiplication of *M. incognita* and increased plant growth in tomato. *P. lilacinus* reduced gall index and significantly increased fruit yield by controlling *M. incognita* in tomato (Ekanayake and Jayasundaram 1994; Goswami *et al.*, 1998). Khan and Goswami (2000) reported that eight g (57.92 x 10^8 spores) *P. lilacinus* inoculated rice grain kg^{-1} soil was considered to be optimum for suppression of *M. incognita* in tomato. They also reported that *P. lilacinus* isolate 6 showed highest percentage (75.00 per cent) of egg parasitism of *M. incognita*. In tomato cv. Pusa Ruby, inoculation of *P. lilacinus* in the second season reduced *M. incognita* in soil by 68.00 per cent (Khan and Goswami, 2002). Cannayane *et al.* (2004) reported that *P. lilacinus* introduced through seed treatment and seedling bare root dip in cowpea, tomato and chilli protected the root surfaces from the invasion of *M. incognita* juveniles by forming hyphal networks through profuse colonization.

Pulses

Native isolate of *P. lilacinus* (Strain PL-Nilgiris) parasitized the eggs of *M. incognita* (race-3) by 48.30 per cent and colonized the developing radicles of blackgram and cowpea when applied as seed treatment *in vitro*. Application of the fungus @ one g PDA grown fungus for 100 g seed reduced gall formation by 40.90 and 44.70 per cent, nematode population by 32.40 and 34.00 per cent and colonized the nematode eggs by 35.50 and 36.90 per cent in blackgram and cowpea respectively (Cannayane and Sivakumar, 1999).

Pant and Pandey (2001) reported that among the three biocontrol agents *viz.*, *Trichoderma harzianum* Rifari, *P. lilacinus* and *Aspergillus niger* van Tieghem 1867 maximum reduction in *M. incognita* population was recorded by *P. lilacinus* in chickpea genotype Type-3.

Spices

P. lilacinus was most effective in the management of *M. incognita* in black pepper vines (Sosamma and Koshy, 1995). *P. lilacinus* suppressed *Meloidogyne* spp. population by 58.30 to 86.90 per cent in cardamom nursery. The number of quality seedlings for transplanting was greater in beds treated with this biocontrol agent (Eapen and Venugopal, 1995). *P. lilacinus* grown on wheat bran applied @ two g kg^{-1} soil resulted in good plant growth parameters and reduced number of galls and egg masses per plant in coriander inoculated with 100 *M. incognita* larvae per pot (Midha *et al.*, 2001).

Betel vine

Acharya *et al.* (1993) reported that application of *P. lilacinus* @ eight g per kg soil significantly reduced *M. incognita* population in soil, root-knot indices and increased leaf yield in betel vine. Maximum vegetative growth of the vine characterized by shoot and root length and weight of both shoot and root was observed in the same fungus treatment. *P. lilacinus* at four and eight g per kg soil significantly reduced *M. incognita* population in soil and root and increased the number of leaves per plant, weight of 100 leaves, shoot and root weight of betel vine (Nakat *et al.*, 1995). An increased yield of 38.30 to 56.40 per cent was recorded when the fungus was applied at eight g per kg soil (Nakat *et al.*, 1998). Hazarika *et al.* (2000) found that at four g kg^{-1} soil inoculum level of *P. lilacinus*, the plant growth and yield of betel vine was increased and the root-knot infestation was decreased. Application of *P. lilacinus* inoculated neem cake @ 10 g $vine^{-1}$ at 60 days interval significantly reduced root-knot nematode infestation and increased the vine growth and leaf yield in betelvine (Jonathan *et al.*, 2000).

Sunflower

P. lilacinus parasitized 48.00 per cent of egg masses of *M. incognita* in sunflower (Sankaranarayanan *et al.*, 1998).

Banana

P. lilacinus (multiplied in neem cake) application @ 15 or 20 g per plant significantly reduced the root gall index, egg masses, eggs, females and soil population of *M. incognita* (Jonathan and Rajendran, 2000b). Devarajan and Rajendran (2002) reported that application of *P. lilacinus* @ 30 g kg^{-1} soil at the time of planting effectively reduced gall index, number of egg masses, per cent egg hatch and soil population of *M. incognita* in banana.

Papaya

Nursery soil treatment with *P. lilacinus* formulation significantly reduced root galling in papaya seedlings (Rao and Naik, 2003).

2.5.2.1.1.2 Effect on *M. javanica*

Zaki (1998) reported that *P. lilacinus* reduced the gall index and increased tomato yield by controlling *M. javanica*. In groundnut cv. GG-2 infested with *M. javanica* race-2, application of *P. lilacinus* @ 50 kg ha^{-1} resulted in lowest root-knot index, higher dry pod yield (upto 25.56 per cent) and fodder yield (upto 21.61 per cent) over the control (Patel *et al.*, 1998).

2.5.2.1.1.3 Effect on other Plant Parasitic Nematodes

P. lilacinus was effective for the management of mature females and cyst of potato cyst nematode (Jatala *et al.*, 1979) and reniform nematode infesting tomato and brinjal (Reddy and Khan, 1988 and 1989). The application of *P. lilacinus* enhanced growth and yield in betelvine by suppressing the burrowing nematode multiplication and extent of root lesions (Sosamma *et al.*, 1990). Ramana and Sarma (1993) reported that

application of *P. lilacinus* significantly suppressed population of root-knot and burrowing nematodes in black pepper and increased total root mass production. Sudha *et al.* (2000) found that in arecanut seedlings, inoculation of *P. lilacinus* followed by nematode significantly reduced *Radopholus similis* (Cobb, 1893) Golden, 1956 population both in roots (one nematode per 10 g root) and soil (11.50 nematode per 250 g soil). The application of *P. lilacinus* at the time of planting was very effective compared to application at 30 or 60 days after planting for the control of *R. similis* in banana (Devarajan and Rajendran, 2001). Manzoor *et al.* (2002) reported that application of *P. lilacinus* (grown in mustard oil cake or rice bran) @ eight g fungal culture kg^{-1} soil significantly reduced *Tylenchulus semipenetrans* Cobb, 1913 population and improved plant growth parameters in khasi Mandarin.

2.5.2.1.2 *Pochonia chlamydosporia* (*Verticillium chlamydosporium*)

V. chlamydosporium is a facultative parasite of eggs and females of cyst and root-knot nematodes (Kerry, 1980). *V. chlamydosporium* was capable of preventing egg hatching of *Meloidogyne* spp. and to colonize eggs by hyphal penetration (Morgan Jones *et al.*, 1983). Siddiqui and Mahmood (1995) reported that *V. chlamydosporium* was more effective than *P. lilacinus* against *Heterodera cajani* Koshy, 1967 in pigeon pea.

Sankaranarayanan *et al.* (2000) reported that *V. chlamydosporium* resulted in 53.70 per cent parasitisation of egg masses of *M. incognita* in tomato. Sankaranarayanan *et al.* (2001) reported 45.60 to 61.00 per cent parasitization of *H. cajani* cysts in pigeon pea by the application of *V. chlamydosporium*. Significant increase in plant height and root weight was also observed.

2.5.2.2 *Bacteria*

There are two groups of bacteria, one which release metabolites that have a killing or inhibitory effect on phytonematodes (species of

Bacillus, Clostridium, Pseudomonas, Azotobacter etc.) and the second group include bacteria which parasitize directly on nematodes, thereby affecting the entry, penetration, reproduction, egg hatching and larval mortality of nematodes (*Pasteuria penetrans* (Thorne, 1940) Sayre and Starr, 1985).

2.5.2.2.1 *Bacillus* spp.

Gokte and Swarup (1988) reported that *Bacillus subtilis* (Cohn) and *Bacillus pumilis* Meyer and Gottheil 1901 isolates exhibited high degree of larvicidal properties against *M. incognita, H. cajani, Heterodera zeae* Koshy and *Heterodera avenae* Wollenweber, 1924 .

Sheela (1991) reported that *B. pumilis, B. subtilis, Bacillus coagulans* Hammer 1915[AL], *Bacillus circulans* Jordan, 1980, Emend, Ford, 1916, *B. macerans* and *Bacillus licheniformis* (Weigmann 1898) Chester 1901 have ovicidal and larvicidal effect on *M. incognita.* In black pepper the number of gall and root-knot indices were reduced significantly by *B. macerans* and *B. circulans*. The biometric characters like length of vine, number of leaves, fresh and dry weight of shoot of pepper plants showed statistically significant improvement from ninth month onwards but root weight showed significant increase from twelfth month to the termination of the experiment. The number of emerging *M. incognita* larvae also reduced to 56.00 per egg mass by *B. macerans* treatment (Sheela *et al.*, 1993). A study conducted by Racke and Sikora (1992) revealed that plant growth promoting rhizobacteria, *Agrobacterium radiobacter* (Smith and Townsend) Conn and *B. sphaeriacus* increased the tuber yield of potato by suppressing the population of *Globodera pallida* Johnstone and Booth, 1983. Oka *et al.* (1993) opined that exposure of *Meloidogyne* juveniles to *B. cereus* inhibited the penetration of the nematodes to tomato roots.

The various formulations of *Bacillus thuringiensis* Berliner were reported toxic to eggs and larvae of *Meloidogyne* sp. Zuckerman *et al.*

(1993) found that application of an isolate of *B. thuringiensis* (CR-371) resulted in lesser population of *M. incognita*.

Moity *et al.* (1998) reported that application of *Bacillus* sp. (B-15) twice to root-knot nematode infested soil significantly reduced the number of egg masses, eggs per plant and second stage larvae in soil and increased the fresh weight of root and shoot in tomato. Culture filtrate of *B. subtilis* caused maximum reduction in cyst and juvenile population of *H. cajani* by 95.20 and 94.30 per cent respectively in blackgram (Latha and Sivakumar, 1998).

Field application of *B. subtilis* significantly reduced root galling and reproduction of *M. incognita* in tomato. Significant improvement in plant growth, leaf pigments and yield of tomato was observed in *B. subtilis* treated plots (Khan and Tarannum, 1999).

B. thuringiensis and *Pseudomonas fluorescens* (Migula) showed nematicidal activity against hatched juveniles and adults of *M. incognita* infecting tomato. The percentage of gall formation and root gall index were decreased when the antagonistic bacteria were introduced prior to nematodes compared to the simultaneous introduction of both the nematode and bacteria (Hanna *et al.*, 1999). Neipp and Becker (1999) observed reduced *Heterodera schachtii* Schmidt, 1871 infection in *B. vulgaris* inoculated with *Bacillus megatherium* de Bary 1884.

Sirohi *et al.* (2000) reported that culture filtrates of *Bacillus* and *Pseudomonas* could cause 80.00 to 90.00 per cent mortality in *Meloidogyne* juveniles. Niknam and Dhawan (2002) reported that *B. subtilis* isolate (Bs*t*) inhibited hatching and caused mortality of immature females and males of *R. reniformis*.

Sheela *et al.* (2004) reported the potential of *B. macerans* (two per cent solution) as dipping of cuttings + drenching in soil seven days after planting in managing *M. incognita* in coleus. In Brinjal *B. macerans*

nursery application @ 25 g m^{-2} + drench seven days after sowing significantly reduced the population of *M. incognita* resulting highest yield (Sheela and Nisha, 2004).

2.5.2.2.2 *Pasteuria penetrans*

P. penetrans, a mycelial endospore forming bacterium, is an obligate parasite of a large number of nematodes and it completes its life cycle in second stage juveniles. The biocontrol potential of *P. penetrans* has been established against *Meloidogyne* spp. by a number of workers (Walia and Dalal, 1994; Melki *et al.*, 1995; Sosamma and Koshy, 1997). Application of *P. penetrans* significantly reduced gall formation, number of *Meloidogyne* larvae and eggs in tomato plants (Sekhar and Gill, 1991; Vargas *et al.*, 1992).

Ahmad *et al.* (1994) reported that *P. penetrans* applied at 2.5 cm soil depth was the most effective method for the control of *M. incognita* in tomato. Concentrations of *P. penetrans* at 25,000, 50,000 and 75,000 spores per g soil with simultaneous presence of *M. incognita* @ two J_2 per g soil reduced nematode population and increased plant growth parameters in tomato (Sharma and Samar, 1995). *P. penetrans* application significantly reduced the population of root-knot nematode and gall index in okra (Walia and Mehta, 2000).

Chand *et al.* (2001) reported that application of *P. penetrans* both in nursery as well as the transplanting stage of tomato significantly improved the plant growth parameters with corresponding reduction in galls and *M. incognita* multiplication. Nursery treatment with *P. penetrans* resulted in significantly less number of galls (51.52 galls per 20 seedlings) compared to untreated control (178.23 galls per 20 seedlings) in brinjal cv. Pusa Purple Long (Karuna *et al.*, 2001).

2.5.3 Organic Amendments

The beneficial effects of organic amendments in reducing the plant parasitic nematodes have gained much importance in recent years. The relevant literature pertaining to this study was reviewed and is being presented.

2.5.3.1 Neem cake

Kamalakshiamma (1986) reported that soil application of neem cake @ 240 g per (2.4 x 2.4 m) significantly reduced the population of root-knot nematode in brinjal.

Neem oil cake @ one t ha^{-1} in trenches near the root zone of betel vine at the time of planting of vines was most effective in controlling the root-knot nematodes and increasing the yield (Acharya and Padhi, 1988). Pandey and Singh (1990) reported that soil amended with neem cake or sawdust reduced the *M. incognita* population significantly in chickpea. Similar results were also reported by Hazarika (1990) on brinjal, Bora (1990) in greengram and Das (1992) in soybean particularly with neem cake amended soil. Neem oil cake @ one kg $palm^{-1}$ $year^{-1}$ was effective in reducing the nematode population and significantly increasing the yield in arecanut, banana and black pepper under arecanut based farming system (Sundararaju and Sudha, 1993).

Soil amendment with neem cake at 0.1, 0.5 and 1.0 per cent w/w reduced infection of *M. incognita* on mungbean *V. radiata* and significantly improved the plant height, but reduced root nodulation (Abid *et al.*, 1995). Kaul and Bhat (1995) reported that spot application of neem cake @ 30 g $plant^{-1}$ was most effective in reducing the larval population of *M. incognita* infesting tomato. It resulted highest increase in yield and 30.60 and 40.60 per cent increase over the control in shoot and root length respectively.

Acid extracts of neem cake at different dilutions enhanced the growth of *V. unguiculata* and reduced the population buildup of nematode (Alagumalai *et al.*, 1995). Neem cake application reduced the population of *M. incognita* and improved the plant growth characters of Japanese mint (Pandey, 1995). Thakur and Darekar (1995) reported that neem cake application @ 35 g plant^{-1} reduced root galling, eggs per egg mass, root-knot index and increased shoot and root length, shoot and root weight and yield of aubergine. Soil amended with neem cake and datura powder were effective for the control of root-knot and root-knot disease complex of okra (Haque *et al.*, 1996).

Rao *et al.* (1997a) reported that use of aqueous extract of neem cake for seed treatment and soil drenching under field conditions was as effective as application of carbofuran at two kg a.i ha^{-1} or neem cake two t ha^{-1} for the management of *M. incognita* in okra. Neem cake application @ 80 q ha^{-1} was more effective than carbofuran @ two kg a.i. ha^{-1} in reducing the nematode population and improving the yield of tomato (Jain and Gupta, 1997$_b$).

Organic amendments *viz.*, sawdust, neem cake and poultry manure each @ 1000 kg ha^{-1} found to be effective against *M. incognita* in reducing the galls and final nematode population with significant increase in yield of carrot (Devi and Das, 1998). Amending the soil with neem cake was effective in reducing gall formation, *M. incognita* population and increasing the yield in ginger (Vadhera *et al.*, 1998) and bottlegourd (Patel *et al.*, 1998). Neem cake and neem dust were found effective in the suppression of root-knot nematode, *M. incognita* in tomato (Jacob and Haque, 1998). Neem cake was the best in improving growth parameters and reducing nematode infection and multiplication in cotton (Vats *et al.*, 1998).

Seenivasan *et al.* (2001) reported that neem cake application @ five g kg^{-1} soil reduced nematode population in roots, number of galls, root gall

index and increased the growth of turmeric plants significantly recording 43.00 and 22.00 per cent increase in pseudostem height and number of tillers respectively over control.

Nema (2001) reported that in betel vine cv. Bangla Budagar application of neem cake at two t ha^{-1} resulted highest reduction in *M. incognita* population (62.11 per cent) and number of galls (57.00 per cent). Neem cake application @ 25 g / 1000 g of soil significantly reduced the number of galls and number of egg masses per plant in mungbean cv. MNH-92 (Shafique *et al.*, 2001). Neem cake application @ 200 g m^{-2} was very effective in reducing the nematode population in kacholam rhizosphere (Rajani, 1998; Rajani *et al.*, 1998; Nisha and Sheela, 2003).

2.5.4 Combination of bioagents and organic amendment

2.5.4.1 Paecilomyces lilacinus + neem cake

Management of the citrus nematode, *T. semipenetrans* based on the application of neem cake and castor cake both at 10 g per plant along with *P. lilacinus* @ four g per plant was found to be effective in reducing the citrus nematode population with consequent increase in the growth of acid lime seedlings (Reddy and Khan, 1991a). Neem cake suspension (five per cent) mixed with spores of *P. lilacinus* was also effective as seed treatment in okra for the management of *M. incognita* under field conditions (Rao *et al.*, 1997a). In chickpea, combined application of *P. lilacinus* at 10 ml (3.5 x 10^7 spores ml^{-1}) and neem cake (1 g kg^{-1}) significantly suppressed the reproduction of *M. incognita* and gall development and increased the plant growth and nodulation (Bhat *et al.*, 1998). In tube rose, split application of *P. lilacinus* in combination with oil cakes *viz.*, castor, pongamia or neem (at planting and 45 days later) under field conditions significantly reduced root gall index, root and soil populations of *M. incognita* and its multiplication compared to single application of *P. lilacinus* and oil cakes at planting (Nagesh *et al.*, 1998a). Rao *et al.* (1998a) reported that root dip treatment of aubergine seedlings in the formulations of *P. lilacinus*

cultured on neem cake extract resulted in significant increase in plant growth parameters and drastic reduction in root-knot index and final population of *M. incognita*. A significant increase in root colonization, propagule density in soil and per cent egg infection by *P. lilacinus* showed a complementary effect of these two biocontrol components.

Nagesh *et al.* (2001a) found that supplementation of castor and neem oil cake with nitrogen, phosphorus and potassium in the form of inorganic fertilizers had an additive effect on the mycelial growth and sporulation of *P. lilacinus* enhancing the antagonistic potential of *P. lilacinus* against root-knot nematode in tomato nursery.

Integrated use of *P. lilacinus* formulations (talc or pesta granules) at the rate of four to six kg $acre^{-1}$ with neem cake (150 kg $acre^{-1}$) increased fungal antagonism against *M. incognita* in chrysanthemum and increased flower yield by 23 to 28 per cent under farmers' field conditions (Nagesh *et al.*, 2001b).

Anver and Alam (2001) reported that integration of *P. lilacinus* with neem cake in the field was highly effective in reducing multiplication of *M. incognita* in soil and increasing the plant growth and oil content of linseed significantly.

P. lilacinus in combination with neem cake was highly effective in reducing the multiplication of soil nematodes and subsequently increasing the plant growth in chickpea (Tiyagi and Ajaz, 2004).

2.5.4.2 V. chlamydosporium + neem cake

Integration of *V. chlamydosporium* with neem leaves / neem cake / pongamia cake gave maximum increase in plant growth parameters, least root galling and *M. incognita* population and highest per cent parasitisation of eggs and egg masses and propagule density of the bioagent in the roots of tomato (Rao *et al.*, 1998b and Reddy *et al.*, 1999). Combined soil application of *V. chlamydosporium* and neem cake on

moderately resistant cultivars reduced the number of root-knots per plant by 85.01 to 97.08 per cent, egg masses by 89.13 to 98.03 per cent, *M. incognita* population by 92.51 to 99.22 per cent and improved the leaf yield by 26.34 to 36.12 per cent over the control in mulberry (Sharma *et al.*, 2001).

2.5.4.3 T. harzianum + neem cake

T. harzianum in combination with neem, karanj and castor oil cakes was effective in increasing the growth of acid lime seedlings and reducing the citrus nematode population both in soil and roots. The parasitization of citrus nematode females increased in the presence of oil cakes (Reddy *et al.*, 1996). Integration of neem cake with *T. harzianum* gave effective control of *M. incognita* infecting tomato and increased root colonization with biocontrol agent (Rao *et al.*, 1997b). *T. harzianum* and neem cake in combination significantly reduced root-knot nematode in chickpea cv. Type-3 (Pant and Pandey, 2002).

2.5.4.4 Other Fungi and Organic Amendments

Incorporation of neem cake / castor cake / neem leaf /pongamia leaf in nursery beds at 400 g m^{-2} followed by application of spore suspension of *P. lilacinus* or *V. chlamydosporium* in tomato and brinjal nursery beds facilitated the effective management of *M. incognita* and *R. reniformis*. Further root dip treatment of seedlings in five per cent aqueous suspension of neem leaf/ cake mixed with spores of *P. lilacinus* or *V. chlamydosporium* for 20-30 minutes before transplanting was effective in the management of *M. incognita* and *R. reniformis* in the main field (Rao and Reddy, 1992 and 1993). *Glomus mosseae* (Nicol and Gerd.) in combination with neem leaf/neem leaf extracts had proved significantly effective in increasing the plant growth parameters of egg plant seedlings and reducing *M. incognita* infestation indicating combined and complementary interactive effect of both components in the management of *M. incognita* due to their synergistic action (Rao *et al.*, 1993). In acid lime,

V. chlamydosporium grown in paddy seeds of four g (containing 2.8×10^4 spores per g) per two kg soil and castor cake at 20 g per two kg soil in combination was effective in increasing the plant growth parameters and reducing *T. semipenetrans* population both in soil and roots (Reddy *et al.*, 1995). Zaki (1998) reported that integration of castor leaves together with fertilizer and *P. lilacinus* increased the efficacy of nematode control in tomato. The residual effect of the treatment on the second crop of tomato showed continued efficacy in controlling *M. javanica* by 29.60 to 56.80 and 26.40 to 57.90 per cent suppression in number of galls and second stage juveniles respectively over the control. Goswami *et al.* (1998) reported that in tomato, when both fungi *A. niger* and *P. lilacinus* was applied at transplantation, 10 days after mustard cake application, better plant vigour was noticed in addition to the reduction in *M. incognita* population. Gladiolus plants treated with combinations of *P. lilacinus* + *T. harzianum* + neem cake or *P. lilacinus* + *T. viride* + neem cake before planting the corms not only controlled *M. incognita* infestation but also *Fusarium* wilt till the harvest of flower spikes (Nagesh *et al.*, 1998b). Khan *et al.* (2000) reported that *P. lilacinus* and *T. harzianum* amended with organic substrate resulted in minimum root galling (70.61 per cent reduction over control) in tomato. Cannayane and Rajendran (2001) reported that integrated application of *P. lilacinus*, *V. chlamydosporium* and oil cakes *viz.*, neem / castor / mahua significantly reduced the *M. incognita* population and increased the yield in brinjal cv. Co-2. Final yield from plots treated with *P. lilacinus*, *V. chlamydosporium* and neem cake was increased by 57.60 per cent compared to 31.00 per cent, 25.50 per cent or 18.00 per cent increase from single application of the respective biocontrol agents. Mojumder *et al.* (2002) reported that in aubergine cv. Pusa Purple Round the combinations of neem products (seed powder and cake) and nematophagous fungi (*P. lilacinus* and *V. chlamydosporium*) were effective in the reduction of gall formation and *M. incognita* population in soil. Goswami and Mittal (2002) reported that

A. niger and *P. lilacinus* along with neem cake resulted in maximum reduction in root-knot nematode population both in soil and root in brinjal.

2.5.5 Combination of two bioagents

2.5.5.1 P. lilacinus + P. penetrans

Dube and Smart (1987) found that *M. incognita* was controlled more effectively and yields of host plants (tomato, tobacco, soybean and chilli) were greater when *P. lilacinus* and *P. penetrans* were applied together in field micro plots than when either was applied alone. Maheswari and Mani (1988) reported the combined efficacy of *P. penetrans* and *P. lilacinus* in the biocontrol of *M. javanica*. They found that simultaneous inoculation of *P. penetrans* (150 mg per kg of soil) and *P. lilacinus* (three g per kg of soil) effectively controlled the *M. javanica* population in tomato. Zaki and Maqbool (1990) reported that combined application of *P. penetrans* and *P. lilacinus* enhanced plant growth parameters such as shoot weight and length in brinjal and significantly reduced root-knot indices in aubergine and mung.

Black pepper plants inoculated with *P. penetrans* and *P. lilacinus* showed significant reduction in *M. incognita* population and root-gall indices while it improved vegetative growth and increased root mass production (Sosamma and Koshy, 1995 and 1997).

2.5.5.2 P. lilacinus + V. chlamydosporium

In mungbean combined use of *P. lilacinus*, *V. chlamydosporium* or *Bradyrhizobium* sp. reduced gall formation by *M. incognita* and significantly increased the height of plants (Haque *et al.*, 1997). Trivedi and Goyal (1998) reported that combined application of *P. lilacinus* and *V. chlamydosporium* effectively controlled *M. incognita* and significantly increased plant growth in *Celosia argentea* L.

2.5.5.3 V. chlamydosporium + P. penetrans

Rao *et al.* (1998c) reported that in nursery *V. chlamydosporium* in combination with *P. penetrans* was effective in increasing plant growth parameters of tomato seedlings. In the main field, integration of both the bioagents was most effective in reducing root galling, number of eggs per egg mass, nematode population in soil and root and in increasing the root colonization and egg parasitization with *V. chlamydosporium*, infection of *M. incognita* females with *P. penetrans* and tomato fruit yield.

Mukhtar *et al.* (2002) reported that in tomato, combined application of *V. chlamydosporium* and *P. penetrans* caused 48.74, 67.25 and 38.30 per cent reduction in number of galls, egg masses and population of *M. javanica* respectively.

2.5.5.4 Other Fungi and Bacteria

The combined effect of the mycorrhizal fungi and *P. lilacinus* gave maximum reduction of galls caused by *M. incognita* in okra (Sharma and Trivedi, 1997). The combination of endomycorrhizal fungus and *P. penetrans* was beneficial for sustainable management of *M. incognita* in tomato. This combination significantly reduced the number of egg masses in root system and increased the parasitization of females by *P. penetrans* (Rao and Gowen, 1998).

Pseudomonas aeruginosa (Schroeter) Migula in combination with either *V. chlamydosporium* or *P. lilacinus* significantly reduced egg mass production and number of juveniles in soil and enhanced the plant growth in guar (Praveen *et al.*, 1998) and mung bean (Siddiqui *et al.*, 1999). Siddiqui and Haque (2000) reported that in tomato, *V. chlamydosporium* and *P. aeruginosa* applied together resulted in better biocontrol effect and plant growth compared with either antagonists alone. Latha *et al.* (2000) reported that a combination of *P. lilacinus* with *T. viride* and

P. fluorescens as seed treatment resulted in less root rot incidence, low population of *H. cajani* and more pod yield in *V. mungo*.

Goswami and Sharma (2001) reported that combined application of *Aspergillus terreus* Thom and *P. lilacinus* significantly reduced the *M. incognita* population, number of galls and promoted plant growth in tomato.

2.5.6 Combination of Bioagents and Chemicals

Maheswari *et al.* (1987) reported that application of *P. penetrans* in combination with aldicarb, miral, sebufos and phorate significantly improved plant growth of tomato by greatly reducing galling due to *M. javanica*. Integration of *P. lilacinus* with carbofuran at one kg a.i. ha^{-1} was found effective in the management of reniform nematode, *R. reniforms* infesting tomato and brinjal (Reddy and Khan, 1988 and 1989). Treatment of tomato plants with a combination of either *Trichoderma* and Vydate (Oxamil) or *Trichoderma* and Nemacur (fenamiphos) significantly decreased disease and root-gall index and improved plant height and shoot dry weight (Stephan *et al.*, 1996). Application of *P. lilacinus* @ four g $plant^{-1}$ (grown on paddy seeds) along with carbofuran at one kg a.i. ha^{-1} found to substantially reduce the citrus nematode population both in soil and roots and increased plant growth parameters (Reddy *et al.*, 1996). In cotton, integration of *P. lilacinus* with fenamiphos resulted in lowest root-knot index and highest seed cotton yield (Vyas *et al.*, 1998). Application of *P. fluorescens* and carbofuran in combination enhanced the yield and improved the vigour of plants in the case of tomato by suppressing the root-knot nematode (Khan, 2000) and cyst nematode, *H. cajani* in soil and root system (Sujatha *et al.*, 2000). Saikia and Das (2001) reported that combined application of *P. lilacinus* two g kg^{-1} soil and carbofuran 1 kg ha^{-1} resulted in highest reduction of galls (60.00 per cent), egg masses (65.00 per cent) and highest values for shoot dry weight (4.60 g), root dry weight (1.58 g) and plant height (52.00 cm).

Carbofuran applied with *P. penetrans* was quite compatible and was the most effective treatment in controlling population of *H. cajani* (Gogoi and Gill, 2001).

Gopinatha *et al.* (2002b) reported that greater parasitisation by *V. chlamydosporium* was recorded when carbofuran was integrated with the fungus than when the fungus was applied alone or in combination with neem cake in tomato. Aldicarb in combination with *P. lilacinus* resulted smallest gall index, number of galls and *M. javanica* population in tomato root zone (Owino, 2003).

2.5.7 Combination of Organic Amendments and Chemicals

Singh *et al.* (1980) recommended combined application of oil cakes and nematicides for effective control of nematode population, since it was found superior to oil cakes alone and only a low concentration of nematicide was required when mixed with oil cakes. Gaur and Mishra (1990) reported combined application of organic amendment (neem cake one t ha^{-1}) and phorate 10 G @ one per cent (w/w) as seed treatment and basal application of aldicarb 10 G @ 40 kg ha^{-1} significantly reduced the plant parasitic nematodes and increased the yield of greengram. Reddy and Khan (1991) reported that integration of neem or karanj oil cake @ 0.50 t ha^{-1} along with carbofuran @ one kg a.i. ha^{-1} was effective in reducing root galling and increasing fruit yield in okra. Neem cake followed by carbofuran treated plots showed minimum gall index in ginger (Mohanty *et al.*, 1992). In chickpea, application of neem cake @ 500 kg ha^{-1} + carbofuran 500 g a.i. ha^{-1} provided 93.20 per cent reduction in the population of *M. incognita*, *R. reniformis* and *Hoplolaimus indicus* Sher, 1963 (Mishra and Goswami, 1993). Goswami and Mishra (1993) reported that application of neem cake @ 250 kg ha^{-1} + carbofuran @ 500 g a.i. ha^{-1} showed 87.00 per cent reduction in population of *M. incognita*, *R. reniformis*, *Tylenchorhynchus vulgaris* Upadhyay *et al.*1972 and

H. indicus. This treatment also exhibited maximum green pod and dry grain yield of pea.

In greengram, poultry manure application @ two t ha^{-1} in combination with seed dressing of carbofuran @ three per cent w/w + neem cake @ one t ha^{-1} were found significantly effective in improving plant growth parameters and yield and reducing the number galls, egg masses and final population of *M. incognita* (Barman and Das, 1993). Sheela *et al.* (1995) reported that application of neem cake @ 2.50 t ha^{-1} at the time of planting and carbofuran 1 kg a.i. ha^{-1} forty five days after planting were effective in reducing *M. incognita* population in soil and root ,root-knot count and increasing the yield of ginger.

Singh and Vinodkumar (1995) reported that neem cake application @ 20 per cent w/w significantly reduced number of root galls and population densities of *M. incognita* in Japanese mint.

Maximum reduction in *M. incognita* multiplication and maximum increase in oil yield of Japanese mint HY – 77 was obtained in neem cake applied soil (Pandey, 1995).

Seed treatment with carbofuran 3 G @ three per cent (w/w) and organic amendments *viz.*, neem cake, poultry manure and mustard oil cake each at two t ha^{-1} alone and combined application of seed dressing followed by organic amendments @ one t ha^{-1} each were found effective in improving plant growth characters and yield of greengram (Barman and Das, 1996). Application of neem cake in the nursery followed by carbofuran @ one kg a.i. ha^{-1} in the main field significantly arrested the rate of multiplication of *M. incognita* and increased the crop yield in tomato (Anitha and Subramanian, 1998).

Neem cake and carbofuran treated plants supported minimum nematode population and root-knots in papaya plants (Mohanty *et al.*, 2000). Keshari and Pathak (2000) reported that neem cake, mustard cake

and press mud @ 25 g kg^{-1} soil and carbofuran 20 and 10 mg a.i. kg^{-1} soil reduced root gall formation and increased the yield (root weight) and shoot length of red beet.

Sudha and Sundararaju (2001) reported that phorate @ 25 g/plant alone or in combination with neem cake @ one kg $plant^{-1}$ was effective in reducing the *R. similis* population in arecanut based cropping system (arecanut, banana and black pepper). In cowpea cv. Pusa Komal the combination of neem cake and carbofuran in reduced dose suppressed the nematode multiplication with an increase in plant vigour (Singh and Goswami, 2001). Chakrabarti and Mishra (2001) reported that combined application of neem products *viz.*, neem cake or neem seed powder with carbofuran or phorate significantly reduced the root population of *M. incognita* in chickpea.

Goswami and Chawla (2002) reported that in *V. radiata* combined application of neem cake and carbofuran at half the rate of sole application resulted in plant growth equivalent to that obtained with neem cake alone and nematode control at par with carbofuran treatment alone.

2.5.8 Integration of physical methods, bioagents, organic amendments

Kuriyan and Sheela (1981) reported that deep ploughing plus nursery treatment of metham sodium @ 25 ml sq m^{-1} plus spot application of aldicarb @ one kg a.i. ha^{-1} had the minimum number of root-knots and population of *M. incognita* in brinjal root. Deep ploughing decreased the nematode population prior to transplanting and when the seedlings raised from nematicide treated nursery were transplanted, there was less chance of increase in nematode population. In tomato simultaneous application of *G. fasciculatum* and *P. lilacinus* inocula in the nursery beds amended with neem cake or use of mycorrhizal seedlings for root dip in *P. lilacinus* spore suspension revealed synergistic interaction of *P. lilacinus* and *G. fasciculatum*. Significant increase in the plant growth parameters of

nursery seedlings and yield of tomato were obtained consequent to rational integration of these components (Rao *et al.*, 1995).

Nagesh and Reddy (1995) opined that in tube rose, using *P. lilacinus* in combination with neem and calotropis leaf extracts as bulb treatment significantly improved the plant growth and reduced *M. incognita* infection and multiplication.

Integration of neem cake @ 400 g/plant, carbofuran @ 20 g/plant and bioagents *G. fasciculatum* @ 50 g culture (containing an average of 20 J_2 larvae of *M. incognita* race-1 infested with *P. penetrans* each of which had an average of 15 spores attached to the cuticle) was found to be most effective in reducing *R. similis* population significantly both in root and soil by more than 50 per cent in banana. The combination treatment improved the growth of pseudostem, plant height, number of leaves and leaf area (Channabasappa *et al.*, 1995).

Eapen and Venugopal (1995) reported that integration of soil solarization and application of *P. lilacinus* and *Trichoderma* spp. significantly suppressed the *M. incognita* population by 58.30 to 86.90 per cent resulting in improvement in growth and quality of seedlings in cardamom nurseries.

Integration of soil solarization, straw mulch 2" thick and formalin 4.00 per cent @ 11.1 ml m^{-2}showed significant increase in the germination of tomato seeds, plant growth parameters and yield, while the weed growth, *M. incognita* population and root-knot count were reduced (Rao *et al.*, 1995).

Transplanting of tomato seedlings in nursery beds treated with neem cake and *P. penetrans* in pits incorporated with *P. lilacinus* effectively managed *M. incognita* and increased tomato fruit yield (Reddy *et al.*, 1997).

Vidya and Reddy (1998) reported that integration of *P. penetrans*, *G. fasciculatum*, carbofuran and neemark (neem extracts) was effective in

enhancing the plant growth and yield of banana, raising cost: benefit ratio to 1: 2.65 and reducing the nematode population both in soil (95.16 per cent over control) and in roots (89.27 per cent).

Subhadra *et al.* (1998) reported that integration of paring and hot water treatment of suckers along with neem cake and carbofuran application was found very effective in reducing the population of *R. similis*, *Helicotylenchus multicinctus* (Cobb, 1893) Golden, 1956 and *M. incognita* both in soil (83.33 per cent) and roots (66.17 per cent) and increasing the plant growth parameters and fruit yield in banana.

Solarization for 15 days and nursery treatment with carbofuran @ 0.30 g a.i. m^{-2} + neem cake treatment @ 200 kg ha^{-1} were effective in increasing the yield of brinjal by reducing the population of *M. incognita* (Sheela and Jiji, 1999).

Integration of *P. penetrans, T. viride* and neem in nursery and rotation of tomato with marigold in the field gave significant reduction in root galling, egg mass production and final *M. incognita* population in soil which resulted in increased tomato yield (Reddy *et al.*, 2000).

Integration of solarization, seed treatment with carbosulfan (Posse 25 ST) @ three per cent a.i (w/w) and application of neem cake @ 200 kg ha^{-1} at sowing significantly reduced nematode population (71.80 per cent reduction) and root-knot index resulting in high yield in okra (Jain and Dabur, 2000).

Solarization in the nursery together with the application of farmyard manure or poultry manure @ 2000 kg ha^{-1} or carbofuran @ two kg a.i. ha^{-1} significantly reduced the population of *M. incognita* and increased the yield of brinjal (Jiji *et al.*, 2000). Solarization alone or combined with low rates of nematicides *viz.*, 1,3-D (50 and 100 l ha^{-1}), dazomet (125 and 250 kg ha^{-1}) and methyl bromide (10 and 20 g m^{-2})

effectively controlled *M. incognita* and significantly increased marketable carrot yield (Vito *et al.*, 2000).

Harish and Gowda (2001) reported that neem cake + carbofuran + *T. viride* was most effective in reducing the nematode population, improving the plant growth and fruit yield (76.30 t ha^{-1}) with a high cost benefit ratio (1: 2.90) in banana.

In brinjal, transplants obtained from the nursery treated with neem cake + *G. mosseae* + *P. lilacinus* were least infected with *M. incognita*. Neem cake amendment in the nursery bed increased the colonization of *G. mosseae* and *P. lilacinus* on the roots of transplants before and after transplanting. The combined effect of these three components facilitated the sustainable management of *M. incognita* in aubergine cv. Pusa Purple Round under field conditions (Rao and Reddy, 2001).

Materials and Methods

3. MATERIALS AND METHODS

Studies were conducted at College of Agriculture, Vellayani during 2002-05 to assess the damage potential of varying population of *Meloidogyne incognita* (Kofoid and White) Chitwood in coleus tubers under micro plot and storage condition, viability of infested tubers during storage and biochemical changes due to nematode infestation. Investigations were also carried out to identify the resistant varieties, potential of various bioagents and organic amendment in comparison with chemical on *M. incognita* under field condition in order to evolve an eco-friendly integrated management strategy in *Solenostemon rotundifolius* (Poir) Morton. The materials used and methods adopted for four major experiments are given below :

3.1 ESTIMATION OF CROP LOSS DUE TO *M. INCOGNITA*

3.1.1 Under Microplot Condition

Study was undertaken to assess the loss incurred in coleus due to *M. incognita* at College of Agriculture, Vellayani by raising the crop in microplots. The microplots of size 1 x 1 m were filled with denematised potting mixture and was made into fine tilth. Coleus cuttings raised in the nursery were transplanted at a spacing of 30 cm between rows and plants. Shade was provided immediately after planting and moistened gently at different intervals.

Newly hatched second stage juveniles of *M. incognita* at different levels were inoculated in the rhizosphere of the transplanted cuttings 15 days after planting. Plants were maintained as per the Package of Practices Recommendations of the Kerala Agricultural University (KAU, 2002).

3.1.1.1 Preparation of Denematised Potting Mixture

The denematised potting mixture was prepared by mixing sieved field soil, sand and well decomposed farmyard manure in the proportion of

2 : 1 : 1 and the mixture was spread on the ground in the form of beds of 15 cm thickness. The beds were divided into blocks of one square feet, which were uniformly moistened with four per cent formaldehyde solution. The beds were then covered with polythene sheets for two weeks. The sheets were removed and the mixture was raked well and exposed for two weeks. This denematized potting mixture was used for microplot and pot culture studies.

3.1.1.2 Culturing of Root-knot Nematode, M. incognita and Maintenance of Pure Culture

Single egg mass of *M. incognita* collected from infested roots of coleus plants was kept in a petridish containing distilled water for hatching. One day old larvae (juveniles) were inoculated in coleus plants maintained in denematized soil in the rhizosphere. Subculturing and multiplication was done periodically in the greenhouse to obtain sufficient number of nematodes for various experiments. The identity of the species is confirmed as *M. incognita* race 3 by using the taxonomic keys and host differentials.

3.1.1.3 Inoculation of M. incognita

Viable egg masses of *M. incognita* were hand picked from the roots of infested plants and kept in cavity blocks containing sterile water. After 24 hours, the nematode suspension contained in the petridish was collected and used as the stock inoculum. The number of larvae per ml of suspension was counted under a binocular stereomicroscope using a counting dish. The larval inoculum was adjusted to required number of larvae per ml of suspension by adding sterile water. Inoculation into the root zone of the plants was done as per the method suggested by Venkitesan and Sethi (1977).

3.1.1.4 Raising of Coleus Cuttings for the Experiment

The seed tubers of coleus, variety Sree Dhara released from Central Tuber Crops Research Institute (CTCRI), Sreekaryam, Thiruvananthapuram, having one healthy sprout was used as planting material. Well developed mature healthy disease free tubers were selected and washed in running

water to remove the soil particles. The tubers were planted at a spacing of 30 x 15 cm in nursery beds containing garden soil. Plants were maintained as per the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2002).

3.1.1.5 Recording Observations

Biometric characters of five observational plants *viz.*, height, number of leaves, number of branches, plant spread were recorded at one, two, three, four and five months after inoculation (MAI). Leaf area index (LAI) was recorded at two, three, four and five MAI. Plant spread in terms of diameter (cm) was recorded by measuring length of the longest lateral branches on both sides using a thread and scale and thus average was found out.

LAI was calculated by the following formula,

$$LAI = \frac{\text{Leaf area}}{\text{Land area}}$$

Leaf area was calculated as detailed below:

Leaves were grouped into small, medium and large and estimated the area by graph paper method. Total leaf area was found out by multiplying estimated area with total number of leaves coming into respective groups (Watson, 1958).

Yield in terms of number of tubers per plant (total and marketable), weight of tubers per plant (total, marketable and edible portion), number of tubers per kg and size of tubers was recorded at the time of harvest. Size of five randomly selected tubers in terms of diameter (cm) was measured by using a thread and scale and thus average was found out.

Population of *M. incognita* was estimated from soil at five months after inoculation by collecting samples of 250g from each plot. Nematodes were extracted from the soil samples adopting Cobb's sieving and decanting technique modified by (Cobb, 1918).

Nematode population characteristics (number of larvae in root (five g) and tuber (10g), root-knot count and root-knot index, number of females and number of egg masses per five g root and average number of eggs per egg mass) were recorded at the time of harvest.

The population of nematodes in root was estimated by the technique as adopted by Hooper (1970). For estimating the number of females, five g root sample of coleus was cut into small bits of two to three cm length and stained by differential staining method using acid fuschsin-lactophenol mixture. The stained roots were pressed between two glass slides and then teased with needle and examined under a microscope to count the number of females.

The estimation of the number of eggs per egg mass, four egg masses were hand picked and kept in sterile water in a petri dish. For assessing the viable eggs per egg mass, the total number of freshly hatched larvae was counted. Then the sterile egg mass was kept between glass slides, crushed thoroughly, stained and examined under the microscope to count the remaining eggs. The number of viable eggs plus the eggs remaining in the egg sac gave the total number of eggs present per egg mass.

The number of galls per g of root were counted and the root-knot index was fixed as per the modified method of Heald *et al.* (1989) as detailed below:

Number of galls per plant	Root-knot index
1 – 5 galls	1
6 – 10 galls	2
11 – 15 galls	3
16 – 20 galls	4
Above 20 galls	5

Experiment on crop loss estimation under micro plot condition

The experimental details were as follows:

Design : RBD

Net plot size : 1 × 1 m

Replications : 4

Treatments

T_1 – Soil inoculated with 100 J_2

T_2 – Soil inoculated with 500 J_2

T_3 – Soil inoculated with 1000 J_2

T_4 – Soil inoculated with 5000 J_2

T_5 – Uninoculated (Denematized soil)

(J_2: second stage juveniles of *M. incognita*)

Five plants were selected at random for recording observations as mentioned in 3.1.1.5.

3.1.2 Under Storage Condition

Uniform sized tubers were collected from the experiment mentioned in 3.1.1 and stored in standard method at room temperature in the laboratory. Samples of tubers (500 g each) randomly collected from the treatments of 3.1.1 were spread on floor and observed for the storage life of tubers. The shrinkage, weight loss, viability and sprouting of tubers were observed at 15 days interval for a period of three months.

3.1.2.1 Germination and Growth Characters of Tubers after Storage

Three months after storage, the tubers from each 500g sample were planted in pots containing denematised potting mixture prepared as mentioned in 3.1.1.1. The germination of tubers and growth characters of plants were observed.

Weight of tubers was taken at 15, 30, 45, 60 and 75 days after harvest . Germination percentage of tubers was recoded three months after storage. Biometric characters of plants (height, number of leaves, number of branches, plant spread and leaf area index) were recorded at one, two and three months after planting as per the method mentioned in 3.1.1.5.

3.2 ESTIMATION OF BIOCHEMICAL CHANGES DUE TO *M. INCOGNITA* INFESTATION

The coleus tubers infested with different levels of *M. incognita* were collected from the experiment on crop loss estimation under micro plot condition (3.1.1). The changes in chemical composition of tubers *viz.* protein, starch, sugar and crude fibre content were estimated. The tubers were dried separately in a hot air oven set at 70°C till constant weights were obtained. Then these tubers were ground to pass through 0.5 mm mesh in a willey mill.

3.2.1 Protein

The nitrogen content in tubers was estimated by modified micro-kjeldahl method (Jackson, 1973). Then the protein content of tubers was calculated by the standard method developed by Simpson *et al.* (1965).

3.2.2 Starch Content

Starch content in healthy and nematode infested tubers was estimated using potassium ferricyanide method (Ward and Pigman, 1970).

3.2.3 Sugars

Sugar content in healthy and infested tubers were estimated by the standard procedure suggested by A.O.A.C. (1969).

3.2.4 Crude Fibre Content

Crude fibre content of the tubers was determined by the method of A.O.A.C. (1975).

Percentage of protein, starch, sugar and crude fibre content was estimated and presented.

3.3 SCREENING FOR VARIETAL RESISTANCE TO *M. INCOGNITA*

Two improved varieties, five lines, two accessions and one local variety were screened for comparing the relative tolerance to *M. incognita*. The trial was laid out in completely randomized design with three replications. The cuttings collected from CTCRI, Vellanikkara, Pattambi and Palappoor were transplanted in pots containing denematized potting mixture prepared as mentioned in 3.1.1.1. The soil was inoculated with *M. incognita* at an inoculum level of one juvenile per g of soil 15 days after planting. One litre denematized soil per pot was applied forty five days after planting to promote tuberisation.

Table 1. Details of varieties / lines / accessions collected for screening

Sl. No.	Variety / Lines / Accessions	Source
1	Line – 74	CTCRI
2	Line – 64	CTCRI
3	Line – 79	CTCRI
4	Line – 76	CTCRI
5	Sree Dhara	CTCRI
6	Line – 71	CTCRI
7	Accession (TC – 9)	Vellanikkara
8	Accession (M – 131)	Vellanikkara
9	Nidhi	Pattambi
10	Palappoor local	Local collection

3.3.1 Observations

Biometeric characters, yield and nematode population characteristics were recorded as per the method mentioned in 3.1.1.5.

Quality parameters (protein, starch, sugar and crude fibre content) of tubers in selected five varieties based on yield attributes were estimated at the time of harvest by following the procedure mentioned in 3.2.1 to 3.2.4.

The root-knot indexing was done by modifying the method of Heald *et al.* (1989) as detailed below:

Number of galls or root-knots per plant	Root-knot index	Reaction
0	0	Highly resistant
1 – 25	1	Resistant
26 – 50	2	Moderately resistant
51 – 75	3	Moderately susceptible
76 – 100	4	Susceptible
>100	5	Highly susceptible

3.4 FIELD EXPERIMENTS ON MANAGEMENT OF *M. INCOGNITA*

3.4.1 Under Nursery Condition

3.4.1.1 Inoculum Production of Bioagents

3.4.1.1.1 Preparation of *Paecilomyces lilacinus* (Thom.) Samson

Conical flasks of 1000 ml capacity were filled with 750 g rice bran and steam sterilized. Nucleus culture of fungus, *P. lilacinus* obtained from Indian Institute of Spices Research, Calicut maintained in potato dextrose agar (PDA) slants was inoculated to sterilized rice bran and allowed to multiply for 15 days. The flasks were shaken at 48 h interval to accelerate growth of the fungus. On the 15th day, the inoculum

developed was recorded as spore load of 10^6 per gram. This inoculum was applied in the nursery @ 30 g m^{-2}.

3.4.1.1.2 Preparation of *Pochonia chlamydosporia* Zare *et al.*, 2001 (*Verticillium chlamydosporium* Goddard)

A pure culture of *P. chlamydosporia* obtained from IARI, New Delhi was used for the study. Conical flasks of 1000 ml capacity were filled with 750 g rice bran and steam sterilized. Stock cultures of the fungus maintained in PDA slants were inoculated to PDA in petriplates and allowed to grow. Fungal discs of five mm diameter were inoculated to rice bran and allowed to multiply for 15 days. The flasks were shaken at 48 h interval to accelerate the growth of the fungus. On 15^{th} day, the spore load of *P. chlamydosporia* was recorded as 10^6 per gram of rice bran. This inoculum was used @ 30 g m^{-2} in nursery.

3.4.1.1.3 Preparation of *Bacillus macerans* Schardinger, 1905

Talc based formulation of *B. macerans* containing 10^6 cells per g prepared in the Nematology Laboratory, College of Agriculture, Vellayani was used for nursery treatment. The inoculum was applied to the soil @ 30 g m^{-2}.

3.4.1.2 Soil Solarization

The experimental area was ploughed to fine tilth and nursery beds were prepared. Then adequate moisture was maintained by watering daily for a week to promote nematode egg hatching and weed seed germination. The beds were covered with 150 gauge LDPE clear film. The edges of the sheets were sealed with soil to keep it in position for maintaining the controlled temperature and moisture in the nursery. After fifteen days, the sheets were removed from the beds and it was raked for a period of five days for proper aeration.

3.4.1.3 Hot water treatment

Coleus tubers were dipped in hot water at 50°C and retained in water for 20 minutes before planting in the nursery beds.

3.4.1.4 Neem cake

Neem cake @100 gm^{-2} was applied to the furrows in nursery beds at a depth of 25 cm from the soil surface before planting the tubers.

3.4.1.5 Carbosulfan

It was applied to the soil in nursery beds @ 0.5 gm^{-2} before planting of tubers.

The experiment was conducted as detailed below:

Design : RBD

Replications : 3

Net plot size : 2 × 2 m

Treatments

T_1 – Solarization for 15 days using 150 LDPE film

T_2 – Hot water treatment of tubers (dip at 50°C for 20 minutes)

T_3 – *Paecilomyces lilacinus* (30 g m^{-2})

T_4 – *Bacillus macerans* (30 g m^{-2})

T_5 – *B. macerans* (30 g m^{-2} – one month after planting)

T_6 – *Pochonia chlamydosporia* (30 g m^{-2})

T_7 – Neem cake (100 g m^{-2})

T_8 – Carbosulfan (0.5 gm^{-2})

T_9 – Untreated

Observations

Pre-treatment population of *M. incognita* in soil and tuber was estimated in the nursery as per the method mentioned in 3.1.1.5.

Germination percentage of tubers was recorded one week after planting. Biometric characters of plants (height, number of leaves, number of branches, plant spread and leaf area index) were taken at one month after planting as per the method described in 3.1.1.5.

Nematode population characteristics (number of larvae in soil (250g), root (five g) and root-knot count per five g root, number of females and egg masses per five gram root and average number of eggs per egg mass) were estimated as per the method given in 3.1.1.5 at one month after planting of tubers.

3.4.2 Under Main field Condition

3.4.2.1 Inoculum Production of Bioagents

The bioagents (*P. lilacinus*, *P. chlamydosporia* and *B. macerans*) obtained as described in 3.4.1.1.1 to 3.4.1.1.3 were applied @ 30 g m^{-2}. In combination treatments the application rate was reduced to 15 g m^{-2}.

3.4.2.2 Preparation of Experimental Field

A buffer crop of bhindi was raised in the experimental area prior to the actual layout of the experiment for building up the nematode population. The crop was maintained in the field for 40 days. When the crop was one week old, roots of coleus plants heavily infested with root-knots were collected, chopped and mixed with soil uniformly in various plots. Thirty days after inoculation, the aerial parts of the plants were cut at their base and the roots were ploughed into the plots.

The above *M. incognita* infested experimental area was dug twice, stubbles were removed and clods were broken. Then the field was laid out into blocks and plots. Raised beds of 15 cm height were taken in each plot.

3.4.2.3 Raising of Coleus in the Main Field

Coleus cuttings were raised as mentioned in 3.1.4. The treatments viz. bioagents (*P. lilacinus*, *P. chlamydosporia* and *B. macerans*) and neem

cake were applied singly and in combinations in the main field. Carbosulfan was applied as check. Healthy and vigorous cuttings of 10 to 15 cm length were transplanted in the experimental field at a spacing of 30 cm between rows and plants. Shade was provided immediately after planting and uniform irrigation was given. Plants were maintained as per the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2002).

The details of field trial as detailed below.

Design : RBD

Net plot size : 2 × 2 m

Replications : 3

Treatments

T_1 – *Paecilomyces lilacinus* (30 g m^{-2})

T_2 – *Bacillus macerans* (30 g m^{-2})

T_3 – *B. macerans* (30 g m^{-2}) one month after planting

T_4 – *Pochonia chlamydosporia* (30 g m^{-2})

T_5 – Neem cake (100 g m^{-2})

T_6 – *P. lilacinus* (15 g m^{-2}) + *B. macerans* (15 g m^{-2})

T_7 – *P. lilacinus* (15 g m^{-2}) + *P. chlamydosporia* (15 g m^{-2})

T_8 – *P. chlamydosporia* (15 g m^{-2}) + *B. macerans* (15 g m^{-2})

T_9 – *P. lilacinus* (15 g m^{-2}) + Neem cake (100 g m^{-2})

T_{10} – *B. macerans* (15 g m^{-2}) + Neem cake (100 g m^{-2})

T_{11} – *P. chlamydosporia* (15 g m^{-2}) + Neem cake (100 g m^{-2})

T_{12} – Carbosulfan (0.5 gm^{-2})

T_{13} – Untreated

3.4.2.4 Re-isolation of Bioagents in the Root and Rhizosphere

3.4.2.4.1 Estimation of Population of *B. macerans*, *P. lilacinus* and *P. chlamydosporia*

The population of *B. macerans, P. lilacinus* and *P. chlamydosporia* in the rhizosphere soil was estimated by the dilution plate technique (Johnson and Curl, 1972).

One gram of rhizosphere soil was taken along with root materials and transferred to 100 ml sterile water blank and shaken for five to ten minutes in a shaker. From this stock suspension, different dilutions of 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}, and 10^{-6} were prepared. The population of bacteria and fungi were estimated at 10^{-6} and 10^{-3} dilutions respectively. Nutrient agar medium, Martin's Rose Bengal Agar medium and Potato Dextrose Agar medium were used for plating *B. macerans, P. lilacinus* and *P. chlamydosporia* respectively. The composition of media used is given in Appendix-I. The media prepared was sterilized. Streptomycin sulphate solution (one per cent) was added to the melted media @ three ml l^{-1} at 40°C. One ml aliquotes from the dilutions 10^{-3} and 10^{-6} were transferred to sterile petriplates. The media was poured to petridishes @ 20 ml per dish and rotated gently for thorough mixing and allowed to cool. The petridishes were incubated at 28 ± 1°C for 96 hours. Observations were recorded as number of colony forming units (cfu) per gram of soil.

Observations

Biometric characters, yield and nematode population characteristics were recorded as per the method mentioned in 3.1.1.5.

Quality parameters (protein, starch, sugar. and crude fibre) of tubers selected from main field, based on yield attributes were estimated at the time of harvest of tubers as per the method mentioned in 3.2.1 to 3.2.4.

Re-isolation of bioagents was done and expressed in terms of colony forming units (cfu) as mentioned in 3.4.2.4.

3.4.3 Experiment on Integrated Management of *M. incognita*

3.4.3.1 Inoculum Production of Bioagents

The bioagents (*P. lilacinus*, *P. chlamydosporia* and *B. macerans*) obtained as mentioned in 3.4.1.1.1 to 3.4.1.1.3 were used for soil application.

3.4.3.2 Soil Solarization

Nursery beds were subjected to solarization as described in 3.4.1.2

3.4.3.3 Raising Coleus in the Field

A field experiment was laid out using selected resistant variety (as mentioned in 3.3) along with application of promising treatments from experiments in the nursery (3.3.1) and main field (3.3.2). The cuttings raised as mentioned in 3.1.1.4 were transplanted at a spacing of 30 cm between rows and plants. Shade was provided immediately after planting and uniform irrigation was given. Plants were maintained as per the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2002).

The integrated management trial was conducted as detailed below:

Design : RBD

Replication : 3

Net plot size : 2 x 2 m

Variety : Sree Dhara

Treatments

T_1 – Solarization (N*)+[*P. lilacinus* 15 g m^{-2} + neemcake 100 g m^{-2}] (M*)

T_2 – Solarization (N) + [*P. lilacinus* 15 g m^{-2} + *B. macerans* 15 g m^{-2}] (M)

T_3 – Solarization (N) + Carbosulfan 0.5 g m^{-2} (M)

T_4 – *P. lilacinus* 30 g m^{-2} (N) + [*P. lilacinus* 15 g m^{-2} + Neem cake 100 g m^{-2}] (M)

T_5 – *P. lilacinus* 30 g m^{-2} (N) + [*P. lilacinus* 15 g m^{-2} + *B. macerans* 15 g m^{-2}] (M)

T_6 – *P. lilacinus* 30 g m^{-2} (N) + [Carbosulfan 0.5 g m^{-2}] (M)

T_7 – *B. macerans* 30 g m^{-2} (N) + [*P. lilacinus* 15 g m^{-2} + Neemcake100 g m^{-2}] (M)

T_8 – *B. macerans* 30 g m^{-2} (N) + [*P. lilacinus* 15 g m^{-2} + *B. macerans* 15 g m^{-2}] (M)

T_9 – *B. macerans* 30 g m^{-2} (N) + [Carbosulfan 0.5 g m^{-2}] (M)

T_{10} – Carbosulfan 0.5 g m^{-2} (N) + [*P. lilacinus* 15 g m^{-2} + Neemcake100 g m^{-2}] (M)

T_{11} – Carbosulfan 0.5 g m^{-2} (N) + [*P. lilacinus* 15 g m^{-2} + *B. macerans* 15 g m^{-2}] (M)

T_{12} – Carbosulfan 0.5 g m^{-2} (N) + Carbosulfan 0.5 g m^{-2} (M)

T_{13} – Untreated control

*N – Nursery *M - Mainfield

3.4.3.4 Re-isolation of Bioagents in the Root and Rhizosphere

3.4.3.4.1 Estimation of Population of *B. macerans* and *P. lilacinus*

The recovery of *B. macerans* and *P. lilacinus* was recorded as mentioned in 3.4.2.4.

Observations

Biometric characters of plants, yield and nematode population characteristics were recorded as described in 3.1.1.5.

Quality parameters (protein, starch, sugar. and crude fibre) of tubers was estimated at the time of harvest of tubers as per the method mentioned in para 3.2.1 to 3.2.4.

Re-isolation of bioagents was done and expressed in terms of colony forming units (cfu) as mentioned in 3.4.2.4.

3.5 ASSESSMENT OF RESULTS

3.5.1 Statistical Analysis

The data generated from the experiments (3.1 to 3.4) were subjected to analysis of variance (ANOVA) technique (Cochran and Cox, 1965). The variables which did not satisfy the basic assumption of ANOVA were subjected to angular, logarithmic and square root transformations and then analysed.

Results

4. RESULTS

In the present study, the possible crop loss caused by *M. incognita* in *S. rotundifolius* was assessed under micro plot and storage conditions. The viability of nematode infested tubers and biochemical changes due to nematode infestation were also studied. Screening and management trials were conducted to evaluate the efficacy of varietal resistance, bioagents and organic amendment in protecting the crop from nematode infestation.

4.1 ESTIMATION OF CROP LOSS DUE TO *M. INCOGNITA*

Crop loss incurred by root-knot nematode, *M. incognita* in *S. rotundifolius* was studied under micro plot and storage condition. The changes in chemical composition of tubers were estimated in terms of changes in protein, starch, sugar and crude fibre content using standard procedures. The results obtained are presented in Tables 2 to 10.

4.1.1 Under Micro Plot Condition

The effect of different inoculum levels *viz.*, 100, 500, 1000 and 5000 juveniles (J_2) in reducing the biometric characters, tuber yield and nematode population characteristics was studied and results are presented here.

4.1.1.1 Biometric Characters

Plant Height

The mean plant height (cm) of *S. rotundifolius* during different intervals after inoculation of various levels of *M. incognita,* is presented in Table 2. There was statistically significant variation in the height of plants from 500 J_2 onwards compared to uninoculated at one month after inoculation (MAI). The levels 1000 and 500 J_2 were statistically on par, the values being 19.50 and 20.50 respectively. The

Table 2. Effect of different levels of *M. incognita* on the biometric characters of *S. rotundifolius* at different intervals after inoculation (mean of four replications)

Levels of inoculum	Biometric characters observed at monthly intervals									
	Height of plants (cm)					Number of leaves				
	1 MAI	2 MAI	3 MAI	4 MAI	5 MAI	1 MAI	2 MAI	3 MAI	4 MAI	5 MAI
100 J_2	22.75	29.75	42.25	51.50	55.50	358.50	671.25	872.50	615.00	534.75
500 J_2	20.50	25.00	40.00	45.25	51.00	336.50	656.25	850.00	545.00	505.00
1000 J_2	19.50	21.75	37.75	41.75	48.00	315.75	640.00	830.00	487.75	420.00
5000 J_2	15.75	18.00	26.50	37.50	36.25	275.00	594.50	722.50	427.50	383.75
Uninoculated	25.75	33.00	46.75	60.25	63.50	372.50	705.00	945.00	757.50	726.25
CD (0.05)	3.19	3.73	2.84	2.73	3.77	20.92	23.75	31.23	33.70	29.57

J_2 – Second stage juveniles

MAI – Months after inoculation

plants inoculated with 5000 J_2 recorded minimum plant height of 15.75 cm and it was significantly different from other levels (1000, 500 and 100 J_2) and uninoculated (25.75 cm).

Plants inoculated with different levels of *M. incognita,* except 100 J_2 (29.75cm) showed statistically significant variation from uninoculated (33.00cm) at two MAI. The effect of inoculum levels of 1000 and 500 J_2 was statistically on par giving mean plant height of 21.75 and 25.00 cm respectively. Minimum mean plant height of 18.00 cm was recorded in 5000 J_2 level and it showed significant reduction from all other levels.

There was significant reduction in plant height at three MAI when compared with uninoculated (46.75 cm). The height observed in 100 J_2 inoculated plants was 42.25 cm and it was statistically on par with 500 J_2. The effect of 500 and 1000 J_2 levels was statistically on par with mean plant height of 40.00 and 37.75 cm respectively. The plants inoculated with 5000 J_2 (26.50 cm) recorded significantly lower plant height among the treatments studied.

S. rotundifolius plants showed significant reduction in height compared to the uninoculated (60.25 cm) at four MAI. The effect of the levels 100, 500 1000 and 5000 J_2 was statistically independent with the plants recording a mean height of 51.50, 45.25, 41.75 and 37.50 cm respectively.

During the fifth month (at the time of harvest), there was significant variation among the treatments over the uninoculated. The plants showed significant reduction in height from 100 J_2 (55.50 cm) onwards compared to the uninoculated (63.50 cm). The effect of 500 and 1000 J_2 levels was statistically on par in reducing the plant height, the values being 51.00 and 48.00 cm respectively. Among the treatments, 5000 J_2 inoculated plants showed significantly lower height of 36.25 cm.

Number of Leaves

There was significant variation in mean number of leaves of *S. rotundifolius* inoculated with various levels of *M. incognita* at different monthly intervals. The results are presented in Table 2.

All the treatments except 100 J_2 (358.50) significantly reduced the number of leaves when compared to the uninoculated (372.50) at one MAI. The effect of 500 and 1000 J_2 was statistically on par with mean leaf number of 336.50 and 315.75 respectively. The plants inoculated with 5000 J_2 (275.00) showed significantly lesser number of leaves among the treatments studied.

During the second month, *S. rotundifolius* plants inoculated with *M. incognita* juveniles showed significant reduction in number of leaves compared to the uninoculated (705.00). From the lowest inoculum level of 100 J_2 (671.25) onwards there was significant reduction in number of leaves compared to the uninoculated and it was statistically on par with 500 J_2 (656.25). The effect of 500 and 1000 J_2 (640.00) levels was statistically on par. The lowest number of leaves was recorded by 5000 J_2 (594.50) inoculated plants and it showed significant reduction compared to all other levels. The same trend was observed at three MAI also, the mean leaf number being 872.50, 850.00, 830.00 and 722.50 at 100, 500, 1000 and 5000 J_2 levels respectively.

Regarding the number of leaves at four and five MAI, all the treatments differed significantly from the uninoculated. The effect of 5000, 1000, 500 and 100 J_2 levels was independent statistically and the mean number of leaves ranged from 427.50 to 615.00 at four MAI and 383.75 to 534.75 at five MAI respectively.

Number of Branches

The data on number of branches (Table 3) showed statistically significant reduction at different inoculum levels during various intervals.

Table 3. Effect of different levels of *M. incognita* on biometric characters of *S. rotundifolius* at different intervals after inoculation (mean of four replications)

Levels of inoculum	Biometric characters observed at monthly intervals									
	Number of branches					Plant spread (cm)				
	1 MAI	2 MAI	3 MAI	4 MAI	5 MAI	1 MAI	2 MAI	3 MAI	4 MAI	5 MAI
100 J_2	24.25	40.25	57.50	61.75	74.00	43.25	49.25	63.75	63.25	73.75
500 J_2	22.75	35.00	53.75	54.75	62.25	36.00	45.50	57.25	58.50	65.50
1000 J_2	21.00	32.75	51.25	44.75	56.25	32.25	39.25	53.50	55.00	55.50
5000 J_2	16.75	24.75	41.00	38.75	42.50	28.75	32.50	41.25	43.25	46.25
Uninoculated	29.00	47.00	61.25	65.50	77.75	51.25	58.75	71.25	74.25	85.50
CD (0.05)	2.75	4.36	4.25	4.49	4.56	4.03	4.10	4.50	4.13	5.63

J_2 – Second stage juveniles

MAI – Months after inoculation

As far as the branch number at one MAI is concerned, significant variation was observed in all the treatments compared to the uninoculated. There was significant reduction from the lowest inoculum level of 100 J_2 onwards (24.25) compared to the uninoculated (29.00) and it was statistically on par with 500 J_2. The effect of 1000 and 500 J_2 was statistically on par giving 21.00 and 22.75 branches respectively. Among the treatments tried, 5000 J_2 inoculated plants recorded significantly lower number of branches (16.75).

When the observations were taken at two MAI, there was statistically significant variation between different levels of *M. incognita* and uninoculated. The plants inoculated with 100 J_2 showed significant reduction in number of branches (40.25) as against the uninoculated (47.00). The levels 500 and 1000 J_2 were statistically on par giving 35.00 and 32.75 branches respectively. Minimum mean number of branches (24.75) was recorded by 5000 J_2 inoculated plants and the effect at this level was independent of all other levels

The number of branches recorded at three MAI, showed significant reduction in all treatments except 100 J_2 (57.50) compared to the uninoculated (61.25). The effect of 500 J_2 was statistically on par with 100 and 1000 J_2, the mean number of branches of 53.75, 57.50 and 51.25 respectively. Minimum number of branches (41.00) was recorded by the plants inoculated with 5000 J_2. The effect of this level was significantly superior to other three levels in reducing the number of branches.

Regarding the number of branches recorded at four MAI, all the treatments except 100 J_2 (61.75) differed significantly from the uninoculated (65.50). The effect of 500, 1000 and 5000 J_2 levels was statistically independent with mean number of branches of 54.75, 44.75 and 38.75 respectively. The same trend was recorded at five MAI also, the values being 74.00, 62.25, 56.25 and 42.50 at 100, 500, 1000 and 5000 J_2 levels respectively.

100 J_2

500 J_2

Uninoculated

1000 J_2

5000 J_2

Plate 1. Effect of different levels of *M. incognita* on the biometric characters of *S. rotundifolius*

Plant Spread

The effect of different levels of *M. incognita* on the plant spread of *S. rotundifolius* at different intervals after inoculation is presented in Plate 1.

In the case of plant spread, there was significant reduction between different levels of *M. incognita* compared to the uninoculated (51.25 cm) at one MAI, from the lowest inoculum level of 100 J_2 (43.25 cm) onwards there was significant reduction in plant spread. The effect of 500 and 1000 J_2 was on par with mean plant spread of 36.00 and 32.25 cm respectively. Plants inoculated with 5000 J_2 recorded the lowest plant spread (28.75 cm) and it showed significant reduction compared to all the other levels.

S. rotundifolius plants inoculated with different levels of *M. incognita* showed significant reduction in plant spread compared to the uninoculated at three MAI. There was significant reduction in plant spread from 100 J_2 (63.75 cm) onwards. The levels 500 and 1000 J_2 were statistically on par showing mean plant spread of 57.25 and 53.50 cm respectively. The plants inoculated with 5000 J_2 showed significantly lower plant spread (41.25 cm) among the treatments studied (Table 3).

When the observations were recorded at four MAI, all the treatments showed significant variation in plant spread compared to the uninoculated (74.25 cm). There was significant reduction in plant spread from lowest level of 100 J_2 (63.25 cm) onwards and it was statistically on par with 500 J_2. The effect of 500 and 1000 J_2 levels was statistically on par with mean plant spread of 58.50 and 55.00 cm respectively. The plants inoculated with 5000 J_2 (43.25 cm) showed significant reduction compared to all the other levels.

There was statistically significant variation in plant spread in different inoculum levels compared to the uninoculated at two and five MAI with mean plant spread of 58.75 and 85.50 cm respectively. The

Table 4. Effect of different levels of *M. incognita* on the leaf area index of *S. rotundifolius* at different intervals after inoculation (mean of four replications)

Levels of inoculum	Leaf area index at monthly intervals			
	2 MAI	3 MAI	4 MAI	5 MAI
100 J_2	3.49	3.67	2.83	1.51
500 J_2	3.13	3.32	2.54	1.33
1000 J_2	3.08	3.22	2.41	1.18
5000 J_2	2.91	2.91	2.26	0.93
Uninoculated	4.15	4.57	3.58	2.43
CD (0.05)	0.18	0.22	0.19	0.17

J_2 – Second stage juveniles

MAI – Months after inoculation

effect of 100,500,1000 and 5000 J_2 levels was statistically independent with mean plant spread ranging from 32.50 to 49.25 cm and 46.25 to 73.75 cm at two and five MAI respectively.

Leaf Area Index

Results presented in Table 4 revealed that there was statistically significant variation in leaf area at different intervals.

Regarding the leaf area index, there was statistically significant variation between different levels and uninoculated. The lowest level of 100 J_2 (3.49) showed significant reduction compared to the uninoculated (4.15) at two MAI. The effect of 500 and 1000 J_2 levels was statistically on par with mean leaf area index of 3.13 and 3.08 respectively. Minimum leaf area was recorded by 5000 J_2 inoculated plants (2.91) and it was statistically on par with 1000 J_2. The same trend of result was recorded at four MAI also with mean leaf area index of 2.83, 2.54, 2.41 and 2.26 at 100, 500, 1000 and 5000 J_2 levels respectively.

There was statistically significant reduction in leaf area index between treatments compared to the uninoculated at three MAI. The plants inoculated with 100 J_2 showed a mean leaf area index of 3.67 and it was significantly different from all other levels. The effect of the levels 500 and 1000 J_2 was statistically on par with mean leaf area index of 3.32 and 3.22 respectively. The plants inoculated with 5000 J_2 recorded a minimum leaf area index of 2.91 and this differed significantly from all other treatments.

All the treatments differed significantly in reducing the leaf area index compared to the uninoculated (2.43) at the termination of the study (five MAI). The effect of the levels *viz.* 100, 500, 1000 and 5000 was statistically independent showing mean leaf area index of 1.51, 1.33, 1.18 and 0.93 respectively. The plants inoculated with 100 J_2 also showed statistically significant reduction compared to the uninoculated.

Table 5. Effect of different levels of *M. incognita* on the yield of *S. rotundifolius* (mean of four replications)

Levels of inoculum	Yield parameters observed at harvest								
	Total number tubers per plant	Total number of marketable tubers per plant	Number of tubers per kg	Size of tubers (cm)	Weight of total tubers per plant (g)	Weight of total marketable tubers per plant (g)	Weight of edible portion of tubers per plant (g)	Yield per plot (kg)	Yield (t ha^{-1})
100 J_2	74.75	60.25	90.75	9.50	425.00	340.00	312.50	4.71	11.78
500 J_2	62.50	51.00	121.25	13.50	376.25	320.00	261.75	3.70	9.25
1000 J_2	53.75	39.00	138.00	14.75	357.50	260.00	227.50	2.60	6.50
5000 J_2	44.75	28.75	145.00	15.50	290.00	223.75	195.00	2.51	6.28
Uninoculated	88.75	74.50	89.50	15.25	527.50	405.00	388.75	5.10	12.75
CD (0.05)	6.00	4.85	17.29	2.42	24.58	30.61	22.88	0.22	0.55

J_2 – Second stage juveniles

4.1.1.2 Yield

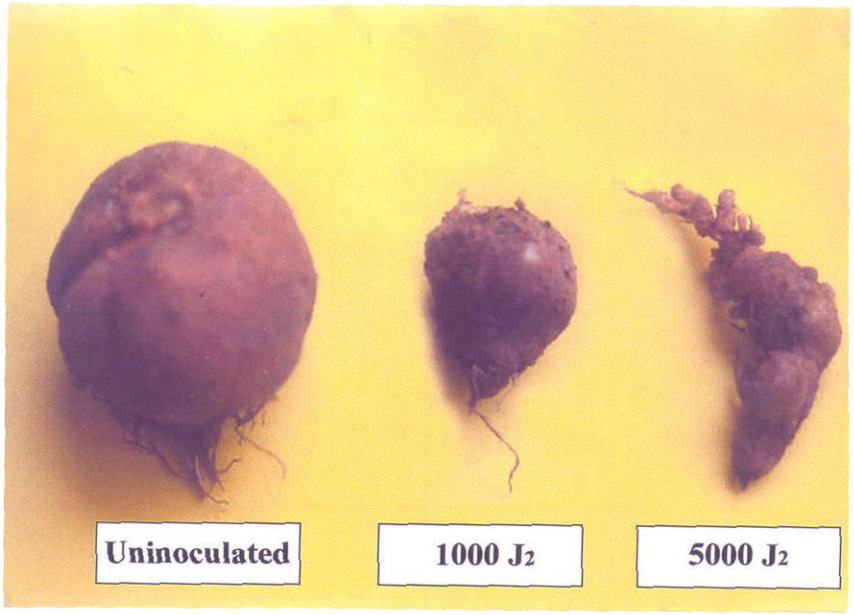
The plants inoculated with different inoculum levels of *M. incognita* showed statistically significant reduction in yield attributing characters *viz.* number (total and marketable), weight (total, marketable, edible portion) of tubers per plant and yield per plot compared to the uninoculated. The results are presented in Table 5.

Regarding the total number of tubers per plant, the effect of 100, 500, 1000 and 5000 J_2 levels was statistically independent with mean number of tubers of 74.75, 62.50, 53.75 and 44.75 respectively. The same trend of result was observed in total number of marketable tubers per plant also. The number of marketable tubers per plant at 100, 500, 1000 and 5000 J_2 was 60.25, 51.00, 39.00 and 28.75 respectively.

In the case of number of tubers per kg, the plants inoculated with 100 J_2 was statistically on par with uninoculated showing a mean number of tubers of 90.75 and 89.50 per kg respectively. The effect of 1000 J_2 (138.00) was statistically on par with 500 and 5000 J_2 with mean number of 121.25 and 145.00 tubers per kg respectively.

Regarding the size of tubers, all other treatments except 100 J_2 (9.50 cm) were found to be on par with uninoculated and the values being 13.50, 14.75 and 15.50 cm at 500, 1000 and 5000 J_2 levels respectively. The diameter and the volume of the tubers increased with increase in inoculum level due to giant cell and gall formation.

Among the treatments significantly lower total weight of tubers per plant was recorded by 500 and 100 J_2 inoculated plants with mean tuber weight of 376.25 and 425.00 g respectively showing statistically significant reduction from uninoculated (527.50 g). The effect of 1000 and 5000 J_2 levels was statistically on par giving 357.50 and 290.00 g respectively. The same trend was observed in yield per plot also, the values being 4.71, 3.70, 2.60 and 2.51 kg at 100, 500, 1000 and 5000 J_2



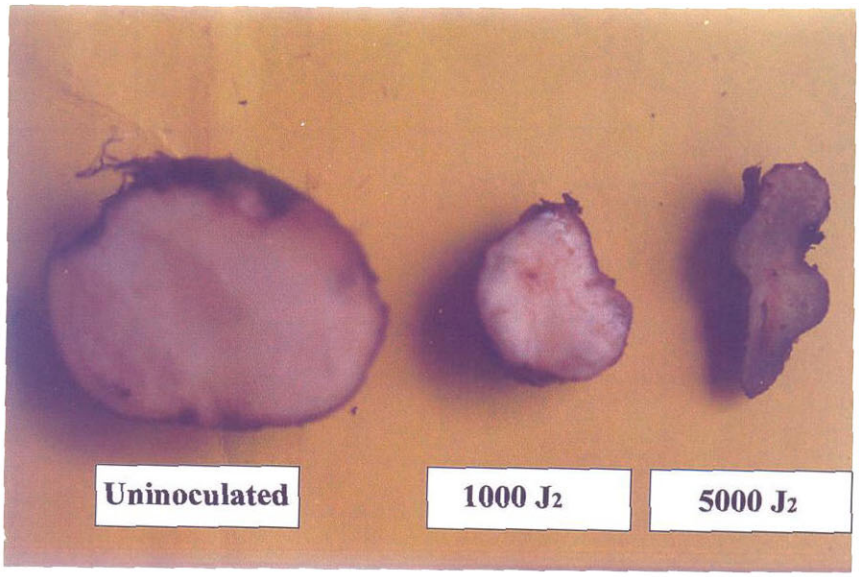


Plate 2. Effect of different levels of *M. incognita* on the appearance of *S. rotundifolius* tubers

Table 6. Effect of different levels of *M. incognita* on the population characteristics in *S. rotundifolius* at the time of harvest (mean of four replications)

Levels of inoculum	Population of nematodes in			Root-knot count in 5 g root	Root-knot index	Number of females in 5 g root	Number of egg masses in 5 g root	Number of eggs per egg mass
	Soil (250 g)	Root (5 g)	Tuber (10 g)					
100 J_2	316.25 (17.81)	147.00 (12.12)	63.75 (8.04)	36.75 (6.14)	2.00	23.50 (4.94)	13.75 (3.82)	83.75 (9.20)
500 J_2	402.50 (20.09)	257.00 (16.05)	148.75 (12.23)	61.50 (7.90)	3.00	58.00 (7.68)	28.75 (5.45)	61.25 (7.88)
1000 J_2	557.50 (23.62)	468.00 (21.64)	198.75 (14.13)	107.25 (10.39)	4.75	74.50 (8.69)	41.25 (6.50)	63.75 (8.04)
5000 J_2	921.25 (30.37)	677.50 (26.04)	251.25 (15.87)	212.50 (14.60)	5.00	95.75 (9.83)	53.75 (7.40)	53.75 (7.39)
Uninoculated	0 (1.00)	0 (1.00)	0 (1.00)	0 (1.00)	-	0 (1.00)	0 (1.00)	0 (1.00)
CD (0.05)	(0.64)	(1.49)	(0.52)	(0.67)	-	(0.49)	(0.38)	(0.50)

J_2 – Second stage juveniles, Figures in parenthesis are after $\sqrt{x + 1}$ transformation

levels respectively. The per hectare yield in the above inoculum levels ranged from 6.28 to 11.78 tonnes. The weight of total and marketable tubers per plant showed significant reduction from the lowest inoculum, 100 J_2 (340.00 g) onwards and it was statistically on par with 500 J_2 (320.00 g). Plants inoculated with 1000 and 5000 J_2 levels showed significant reduction from the other two levels with total marketable tuber weight of 260.00 and 223.75 g per plant respectively. Regarding the weight of edible portion of tubers per plant, the effect of all the treatments was statistically independent among themselves giving mean weight of 312.50, 261.75, 227.50 and 195.00 g at 100, 500, 1000 and 5000 J_2 levels respectively. The appearance of the tubers also contributed to the marketable quality as evidenced from Plate 2.

4.1.1.3 Nematode Population Characteristics

The data presented in Table 6 revealed significant variation between different inoculum levels and uninoculated in reducing *M. incognita* population in soil, root and tuber, number of root-knots, females and egg masses in root and mean number of eggs per egg mass at the time of harvest.

The effect of 100, 500, 1000 and 5000 J_2 levels on population of *M. incognita* in soil, root and tuber, was statistically independent among themselves and the values ranged from 316.25 to 921.25, 147.00 to 677.50 and 63.75 to 251.25 respectively. The recovery of *M. incognita* increased with increase in inoculum level. In the case of number of root-knots, females and egg masses also a similar trend was observed with mean values ranging from 36.75 to 212.50, 23.50 to 95.75 and 13.75 to 53.75 respectively. A different trend was observed in number of eggs per egg mass. The mean number of eggs per egg mass was 53.75 at 5000 J_2 and it increased to 63.75 and 61.25 at 1000 and 500 J_2 level respectively. The effect of 500 and 100J_2 was statistically on par. At 100 J_2 level, the average number of eggs per egg mass was 83.75. The number of eggs per

Table 7. Effect of different levels of *M. incognita* on the weight of tubers of *S. rotundifolius* at different intervals of storage (mean of four replications)

Levels of inoculum	Mean weight of tubers at different intervals of storage (g)						
	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	Percentage weight reduction of tubers 90 DAS over initial sample weight of 500 g
100 J_2	446.25	382.50	325.00	266.25	115.00	66.00	86.80
500 J_2	370.00	310.00	242.50	166.25	75.00	15.75	96.85
1000 J_2	272.50	79.25	-	-	-	-	-
5000 J_2	11.25	-	-	-	-	-	-
Uninoculated	492.75	481.25	471.75	461.25	452.00	437.50	12.50
CD (0.05)	23.27	20.52	22.57	17.39	27.48	13.96	-

J_2 – Second stage juveniles

DAS – Days after storage

egg mass was reduced with increasing inoculum level due to decrease in nutrient absorption by the adult female.

4.1.2 Under Storage Condition

The loss in weight due to infestation by different levels of *M. incognita* juveniles in *S. rotundifolius* tubers harvested from microplots kept under storage condition was estimated and results are presented in Table 7.

All the treatments showed significant variation compared to the uninoculated (492.75 g) at 15 days after storage (DAS). Significant variation was observed among treatments also, the values being 446.25, 370.00, 272.50 and 11.25 g at 100, 500, 1000 and 5000 J_2 levels respectively.

Tubers from 5000 J_2 inoculated plants were deteriorated and the contents turned into a dark brown watery mass with a bad odour at 30 DAS. Those from 1000 J_2 inoculated plants recorded a mean weight of 79.25 g. There was statistically significant reduction in tuber weight in 500 and 100 J_2 inoculated samples showing 310.00 and 382.50 g respectively compared to the uninoculated with mean tuber weight of 481.25 g.

The tubers from the 1000 J_2 inoculated plants also deteriorated at 45 DAS. The samples from 500 and 100 J_2 inoculated plants recorded mean tuber weights of 242.50 and 325.00 g respectively and these two levels showed statistically significant reduction from the uninoculated (471.75 g). The same trend was observed at 60, 75, 90 DAS with mean tuber weight ranging from 66.00 to 266.25 and 15.75 to 166.25 g at 100 and 500 J_2 levels respectively. In uninoculated, the tubers were fully fit for consumption, seed purpose and marketing etc. even three months after storage. The percentage weight reduction of tubers obtained at 90 DAS

Table 8. Effect of different levels of *M. incognita* on germination and growth characters of *S. rotundifolius* at different intervals (mean of four replications)

Levels of inoculum	Percentage of germination	Biometric characters observed at monthly intervals					
		Height of plant (cm)			Number of leaves		
		1 MAP	2 MAP	3 MAP	1 MAP	2 MAP	3 MAP
100 J_2	42.37 (40.59)	14.50	26.50	30.00	123.50	282.50	305.00
500 J_2	7.47 (15.85)	10.50	19.00	22.75	111.25	215.00	247.50
Uninoculated	100.00 (90.00)	19.25	30.50	37.25	132.50	315.00	358.00
CD (0.05)	(11.61)	1.90	2.92	3.18	8.71	23.09	17.71

Figures in parenthesis are after angular transformation

Table 9. Effect of different levels of *M. incognita* on the growth characters of *S. rotundifolius* at different intervals (mean of four replications)

Levels of inoculum	Biometric characters observed at monthly intervals							
	Number of branches			Plant spread (cm)			Leaf area index	
	1 MAP	2 MAP	3 MAP	1 MAP	2 MAP	3 MAP	2 MAP	3 MAP
100 J_2	8.75	11.50	15.50	33.50	44.50	46.25	3.55	4.16
500 J_2	7.00	8.75	11.50	22.25	27.75	30.50	3.09	3.24
Uninoculated	11.50	13.00	25.50	37.50	53.50	55.50	4.39	5.13
CD (0.05)	1.66	1.66	2.97	2.54	3.49	2.65	0.28	0.36

J_2 – Second stage juveniles, MAP – Months after planting

over the initial sample weight of 500 g was 86.80, 96.85 and 12.50 in 100, 500 and uninoculated respectively.

4.1.2.1 Germination and Growth Characters

The results on the germination per cent and growth characters of *S. rotundifolius* on planting tubers collected from plants inoculated with different inoculum levels of *M. incognita* three months after storage are presented in Tables 8 and 9.

Very low germination percentage of tubers was observed from 500 J_2 inoculated plants (7.47) and it showed significant reduction compared to 100 J_2 (42.37) and uninoculated (cent) at three MAS.

There was significant variation in biometric characters of plants raised from tubers collected from micro plots under various treatments and stored for three months compared to the uninoculated except in number of branches at two MAP. Minimum plant height of 10.50 cm was recorded by plants raised from tubers collected from 500 J_2 inoculated plants and it was significantly different from plants raised from 100 J_2 inoculated tubers (14.50 cm) at one month after planting (MAP). The same trend was observed at two and three MAP with plant height ranging from 19.00 to 26.50 and 22.75 to 30.00 cm respectively.

In the case of number of leaves also there was significant variation at monthly intervals both at 100 and 500 J_2 levels. Minimum number of leaves of 111.25 was recorded by plants from 500 J_2 inoculated tubers at one MAP. It showed significant reduction from the plants raised from 100 J_2 inoculated tubers (123.50) and uninoculated (132.50). The same trend was observed at two and three MAP with mean number of leaves ranging from 215.00 to 282.50 and 247.50 to 305.00 respectively.

The plants raised from 500 J_2 inoculated tubers showed significant reduction in number of branches with mean number of 7.00, 8.75 and

Table 10. Effect of different levels of *M. incognita* on the chemical constituents of *S. rotundifolius* tubers after harvest (mean of four replications)

Levels of inoculum	Protein (g / 100 g dry weight of tuber)	Percentage increase of protein over the uninoculated	Starch (g / 100 g dry weight of tuber)	Percentage decrease of starch over the uninoculated	Sugar (g / 100 g dry weight of tuber)	Percentage decrease of sugar over the uninoculated	Crude fibre (g / 100 g dry weight of tuber)	Percentage decrease of crude fibre over the uninoculated
100 J_2	8.38	12.94	17.70	6.32	3.42	8.06	1.28	18.99
500 J_2	8.41	13.34	16.54	9.91	3.13	15.86	1.01	36.08
1000 J_2	8.42	13.48	15.62	14.90	3.08	17.20	0.67	57.59
5000 J_2	8.49	14.42	12.24	33.33	3.07	17.47	0.60	62.03
Uninoculated	7.42	-	18.36	-	3.72	-	1.58	-
CD (0.05)	0.55	-	0.47	-	0.35	-	0.33	-

J_2 – Second stage juveniles

11.50 at one, two and three MAP, while in those from 100 J_2, it was 8.75, 11.50 and 15.50 respectively.

There was statistically significant reduction in plant spread and leaf area index also compared to the uninoculated. At one MAP, minimum plant spread of 22.25 cm was recorded by plants from 500 J_2 inoculated tubers while at two and three MAP, it was 27.75 and 30.50 cm respectively. The plants raised from 100J_2 inoculated tubers recorded mean plant spread of 33.50, 44.50 and 46.25 cm respectively at one, two and three MAP. In the case of leaf area index, plants raised from 500 J_2 inoculated tubers recorded mean leaf area index of 3.09 and 3.24 respectively at two and three MAP. For 100 J_2 it was 3.55 and 4.16 respectively at two and three MAP.

4.2 BIOCHEMICAL CHANGES DUE TO *M. INCOGNITA* INFESTATION

Qualitative loss due to infestation by various levels of *M. incognita* in tubers of *S. rotundifolius* was assessed in terms of changes in protein, starch, sugar and crude fibre contents and the results are presented in Table 10.

Protein

All the treatments showed statistically significant variation in content of protein compared to uninoculated (7.42 g per 100 g dry weight of tubers). The effect of 5000, 1000, 500 and 100 J_2 levels was statistically on par with protein content of tubers ranging from 8.38 to 8.49 g per 100 g dry weight of tubers.

Starch

There was significant variation in the starch content of *S. rotundifolius* tubers at different inoculum levels compared to the uninoculated (18.36 g per 100 g dry weight of tubers). The effect of 5000, 1000, 500 and 100 J_2 levels was statistically independent with mean starch

content of 12.24, 15.62, 16.54 and 17.70g per 100 g dry weight of tuber respectively.

Sugar

In the case of sugar content of tubers, there was statistically significant variation between different inoculum levels and uninoculated (3.72 g per 100 g dry weight) except 100 J_2 (3.42 g per 100 g dry weight of tubers). The tubers of 500 and 100 J_2 inoculated plants showed 15.86 and 8.06 per cent reduction in sugar content over the uninoculated and these effects were statistically on par. The percentage reduction in sugar content at 1000 and 5000 J_2 levels was 17.20 and 17.47 respectively.

Crude Fibre Content

All the treatments except 100 J_2 (1.28 g per 100 g dry weight of tuber) showed significant reduction in crude fibre content of *S. rotundifolius* tubers at various inoculum levels of *M. incognita* compared to the uninoculated (1.58 g per 100 g dry weight of tubers). The tubers from plants inoculated with 500 J_2 showed 36.08 per cent reduction over the uninoculated and this was statistically on par with 100 J_2 (18.99 per cent). The effect of 1000 and 5000 J_2 was statistically on par giving 57.59 and 62.03 per cent reduction over the uninoculated respectively.

4.3 SCREENING FOR VARIETAL RESISTANCE TO *M. INCOGNITA*

The reaction of two varieties (Sree Dhara and Nidhi), five coleus lines (CTCRI-74, CTCRI-64, CTCRI-79, CTCRI-76, CTCRI-71), two accessions from Vellanikkara (TC-9 and M-131) and one local variety (Palappoor local) as check against *M. incognita* was assessed. The data on biometric characters, yield and nematode population are presented in Tables 11 to 17.

Table 11 Reaction of different varieties / lines / accessions of *S. rotundifolius* against *M. incognita* recorded as biometric characters (mean of four replications)

Treatments	Biometric characters observed at monthly intervals									
	Height of plants (cm)					Number of leaves				
	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP
CTCRI line – 74	21.67	29.00	41.33	50.00	58.00	390.00	663.33	936.67	836.67	626.67
CTCRI line – 64	21.00	28.00	38.67	50.00	57.67	370.00	650.00	923.33	823.33	626.67
CTCRI line – 79	20.33	28.00	37.33	49.00	55.67	363.33	646.67	916.67	813.33	580.00
CTCRI line – 76	20.00	27.67	35.33	48.33	55.00	333.33	640.00	880.00	753.33	573.33
Sree Dhara	22.33	30.00	41.67	52.33	63.67	420.00	733.33	970.00	853.33	650.00
CTCRI line – 71	19.67	26.00	35.00	48.00	55.00	330.00	640.00	870.00	743.33	543.33
Vellanikkara accession–TC 9	17.00	23.33	34.67	40.00	46.67	320.00	573.33	846.67	730.00	516.67
Vellanikkara accession–M 131	18.00	25.00	35.00	46.67	53.00	326.67	633.33	856.67	740.00	540.00
Nidhi	22.00	29.67	41.67	51.67	58.33	406.67	716.67	950.00	836.67	646.67
Palappoor local	16.33	20.33	27.67	33.33	35.00	310.00	566.67	835.00	710.00	500.00
CD (0.05)	3.22	4.52	5.18	5.77	9.79	35.86	49.46	37.19	36.26	36.13

MAP – Months after planting

4.3.1 Biometric Characters

There was statistically significant variation in biometric characters *viz.* plant height, number of leaves, number of branches, plant spread and leaf area index. The results are presented in Tables 11 to 13.

Plant Height

In the case of plant height recorded at monthly intervals, all the varieties/lines/accessions showed statistically significant variation compared to the susceptible check, Palappoor local except at one and four months after planting (MAP). Variety Sree Dhara, Nidhi, CTCRI line-74, CTCRI line-64, CTCRI line-79, CTCRI line-76 and CTCRI line-71 recorded significantly higher plant height compared with the susceptible check, Palappoor local (16.33 cm) and two accessions from Vellanikkara (TC-9and M-131) with mean plant height of 17.00 and 18.00 cm respectively at one MAP. The performance of Sree Dhara, Nidhi and CTCRI lines (74, 64, 79, 76 and 71) was statistically on par with mean plant height ranging from 19.67 to 22.33 cm. Similar trend was observed at five MAP also and the height of plants ranged from 55.00 to 63.67 cm. During the second and third month after planting all the varieties /lines / accessions showed significant superiority over the susceptible check in height of plants and the values ranged from 23.33 to 30.00 and 34.67 to 41.67 cm respectively. At four MAP, except Vellanikkara accession – TC 9 (40.00 cm) and susceptible check, Palappoor local (33.33 cm), all the others were at par and recorded a mean plant height ranging from 46.67 to 52.33 cm (Table 11).

Number of Leaves

The number of leaves recorded at various monthly intervals, in all the varieties/lines/accessions showed statistically significant variation compared to the susceptible check, Palappoor local except at one and two MAP. The performance of variety Sree Dhara (420.00) was statistically

on par with variety Nidhi (406.67) and CTCRI-74 (390.00) in number of leaves at one MAP. The effect of CTCRI line-64 and 79 was statistically on par with mean number of leaves of 370.00 and 363.33 respectively. The same trend was observed at three MAP also with mean number of leaves ranging from 916.67 to 970.00. But at two MAP, except Vellanikkara accession TC-9 (573.33) all the others showed significant superiority in number of leaves over the susceptible check, Palappoor local (566.67). Varieties Sree Dhara and Nidhi were statistically on par and recorded an average of 733.33 and 716.67 leaves respectively and the rest of the lines/ accessions recorded mean number of leaves ranging from 640.00 to 663.33. The performance of Sree Dhara, Nidhi, CTCRI-74 and CTCRI-64 was statistically on par and the number of leaves ranged from 823.33 to 853.33 and 626.67 to 650.00 respectively at four and five MAP. There was no statistically significant variation among CTCRI line-76, CTCRI line-71, Vellanikkara accession-TC 9 and Vellanikkara accession-M 131 at four MAP with mean number of leaves ranging from 730.00 to 753.33. At the final stage of the crop (five MAP) CTCRI line-79 and 74 showed significant superiority over CTCRI line-71, Vellanikkara accession TC-9 and M-131 with mean number of leaves ranging from 516.67 to 580.00 (Table 11).

Number of Branches

The performance of variety Sree Dhara (19.00) was statistically on par with Nidhi (17.00), CTCRI-74 (16.67) and CTCRI-64 (16.33) in number of branches at one MAP. The same trend was observed at three MAP also with mean number of branches being 35.00, 34.67, 33.67 and 33.00 respectively. CTCRI lines 79,76,71 and Vellanikkara accessions TC-9 and M-131 were statistically on par and significantly superior to the susceptible check (10.00) with mean number of branches ranging from 13.00 to 15.67 at one MAP. At four MAP, except CTCRI-71 (35.00), Vellanikkara accessions, M-131 (34.33) and TC-9 (32.33), and the Palappoor local

Table 12 Reaction of different varieties / lines / accessions of *S. rotundifolius* against *M. incognita* recorded as biometric characters (mean of four replications)

Treatments	Biometric characters observed at monthly intervals									
	Number of branches					Plant spread (cm)				
	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP
CTCRI line – 74	16.67	27.67	33.67	40.67	42.00	42.00	52.00	63.33	69.00	76.67
CTCRI line – 64	16.33	25.33	33.00	40.00	41.33	40.00	51.33	62.67	68.00	75.33
CTCRI line – 79	15.67	24.67	29.67	38.00	40.67	40.00	50.00	61.67	67.67	73.67
CTCRI line – 76	15.33	24.33	28.33	38.00	40.00	39.00	48.67	61.00	66.67	72.33
Sree Dhara	19.00	29.33	35.00	42.33	45.00	48.00	60.00	64.67	75.00	84.67
CTCRI line – 71	14.67	20.33	27.33	35.00	37.67	38.67	46.00	60.00	65.67	72.33
Vellanikkara accession–TC 9	13.00	18.33	22.33	33.33	35.33	30.00	37.33	58.33	62.33	68.33
Vellanikkara accession–M 131	13.67	20.00	25.00	34.33	36.67	35.00	45.33	60.00	62.33	69.33
Nidhi	17.00	28.67	34.67	42.00	43.33	46.33	60.00	64.33	71.33	77.67
Palappoor local	10.00	17.67	22.33	32.33	35.00	30.00	36.67	52.00	54.00	59.00
CD (0.05)	2.75	4.91	4.18	4.72	4.76	5.69	5.04	6.12	6.92	6.62

MAP – Months after planting

(33.33) all others performed equally well giving mean number of branches ranging from 38.00 to 42.00 The performance of Sree Dhara, Nidhi, CTCRI-74, CTCRI-64 and CTCRI-79 was statistically on par at two and five MAP with mean number of branches ranging from 24.67 to 29.33 and 40.67 to 45.00 respectively (Table 12).

Plant Spread

In the case of plant spread (Table 12), there was significant variation among varieties/lines/accessions in plant spread compared to the susceptible check at monthly intervals except at one and two MAP. The performance of variety Sree Dhara (48.00 cm) was statistically on par with Nidhi (46.33 cm) and these two showed significant superiority over all other lines / accessions at one MAP. CTCRI lines-74, 64,79,76 and 71 were significantly superior to Vellanikkara accessions M-131 (13.67), TC-9 (13.00) and susceptible check, Palappoor local (30.00) with mean plant spread ranging from 38.67 to 42.00. At two MAP except Vellanikkara accession TC-9 and susceptible check, all the others showed significantly higher plant spread with values ranging from 45.33 to 60.00 cm. At three MAP, except Vellanikkara accession–TC-9 (58.33 cm) and Palappoor local (52.00 cm), all the others performed equally well with mean plant spread ranging from 60.00 to 64.67 cm. The performance of Sree Dhara (75.00 cm) was on par with Nidhi (71.33 cm) and CTCRI line-74 (69.00 cm) at four MAP and these three showed significant superiority over all the other lines/ accessions. The CTCRI lines-64, 79, 76, 71 and Vellanikkara accessions TC-9 and M-131 were at par with mean plant spread ranging from 62.33 to 68.00 cm. At five MAP, Sree Dhara established its superiority over all other lines / varieties / accessions with mean plant spread of 84.67 cm. It was followed by Nidhi, CTCRI-74, CTCRI-64, CTCRI-79, CTCRI-76 and CTCRI-71 which were at par, the values being 77.67, 76.67, 75.33, 73.67, 72.33 and 72.33 cm respectively (Plate 5).

Table 13 Reaction of different varieties / lines / accessions of *S. rotundifolius* against *M. incognita* in terms of leaf area index (mean of three replications)

Treatments	Leaf area index at monthly intervals			
	2 MAP	3 MAP	4 MAP	5 MAP
CTCRI line – 74	4.02	3.97	3.65	1.63
CTCRI line – 64	3.80	3.80	3.38	1.50
CTCRI line – 79	3.75	3.60	3.03	1.33
CTCRI line – 76	3.53	3.43	2.87	1.33
Sree Dhara	4.50	4.72	3.76	1.82
CTCRI line – 71	3.51	3.41	2.74	1.33
Vellanikkara accession – TC 9	2.73	2.64	2.18	1.27
Vellanikkara accession – M 131	2.88	2.93	2.43	1.30
Nidhi	4.40	4.30	3.65	1.70
Palappoor local	2.40	2.40	1.92	0.93
CD (0.05)	0.34	0.49	0.36	0.30

MAP – Months after planting

Leaf Area Index

With respect to leaf area index, variety Sree Dhara (4.50) was statistically on par with Nidhi (4.40) at two MAP. At three MAP also similar trend was observed with mean leaf area index of 4.72 and 4.30 respectively. The CTCRI lines, 74, 64 and 79 were statistically on par at two and three MAP with mean leaf area index ranging from 3.75 to 4.02 and 3.60 to 3.97 respectively. At two MAP, the rest of the lines/ accessions showed significant superiority over the susceptible check, Palappoor local (2.40) with mean leaf area index ranging from 2.73 to 3.53. However at three MAP, CTCRI lines-76, 71 and Vellanikkara accession M-131 were statistically on par and significantly superior to Vellanikkara accession TC-9 and Palappoor local, the mean leaf area index being 3.43, 3.41, 2.93, 2.64 and 2.40 respectively. The CTCRI lines 64,79,76,71 and Vellanikkara accession M-131 were also significantly superior to the susceptible check, Palappoor local (1.92) and Vellanikkara accession TC-9 (2.18) with mean leaf area index ranging 2.43 to 3.38 at four MAP. At five MAP The performance of CTCRI lines 64, 79, 76, 71 and Vellanikkara accessions (M-131 and TC-9) was statistically on par and better than susceptible check, Palappoor local (0.93) recording mean leaf area index to the tune of 1.27 to 1.50 (Table 13).

4.3.2 Yield

The yield of coleus varieties/lines/ accessions in terms of total number and weight of tuber per plant are presented in Table 14.

In the case of number of tubers, all the varieties/lines/accessions, except Vellanikkara accession M-131 (43.33) and TC-9 (43.00) showed significant superiority over the susceptible check, Palappoor local (42.00). Among the varieties/lines/accessions, variety Sree Dhara (81.00) recorded statistically similar effect as that of Nidhi (75.67) and CTCRI line-74 (75). CTCRI lines 64 and 79 recorded total mean number of tubers of 67.33 and 57.67 per plant respectively and these two were statistically on par and

Table 14. Reaction of different varieties / lines / accessions of *S. rotundifolius* against *M. incognita* in terms of yield and yield attributing characters (mean of three replications)

Treatments	Yield parameters observed at harvest						
	Total number of tubers per plant	Total number of marketable tubers per plant	Number of tubers per kg	Size of tubers (cm)	Weight of total tubers per plant (g)	Weight of total marketable tubers per plant (g)	Weight of edible portion of tubers per plant (g)
CTCRI line – 74	75.00	38.33	93.67	16.00	480.00	390.00	253.33
CTCRI line – 64	67.33	35.33	94.00	15.50	426.67	300.00	230.00
CTCRI line – 79	57.67	28.33	100.33	14.83	411.67	296.67	230.00
CTCRI line – 76	52.33	27.67	107.00	14.33	383.33	280.00	213.33
Sree Dhara	81.00	44.00	85.00	17.50	550.00	446.67	370.00
CTCRI line – 71	50.67	25.33	109.00	14.17	336.67	271.67	213.33
Vellanikkara accession – TC 9	43.00	25.00	105.67	12.67	330.00	236.67	203.33
Vellanikkara accession – M 131	43.33	23.00	109.00	13.83	376.67	270.00	210.00
Nidhi	75.67	41.00	91.00	16.00	521.67	410.00	346.67
Palappoor local	42.00	22.33	110.00	12.00	311.67	223.33	200.00
CD (0.05)	10.39	5.78	8.93	2.48	39.97	37.86	33.92

inferior to above three. The performance of CTCRI lines 76 and 71 was statistically on par with mean tuber number of 52.33 and 50.67 per plant respectively.

Regarding the marketable number of tubers per plant, the performance of Sree Dhara, Nidhi and CTCRI line-74 was on par with mean number of 44.00, 41.00 and 38.33 respectively. CTCRI line-64 showed significant superiority over all other lines/accessions in marketable number of tubers but was inferior to the above three recording mean tuber number of 35.33 per plant. The performance of CTCRI lines 76, 71 and Vellanikkara accessions TC-9 and M-131 was statistically on par to the susceptible check, Palappoor local with mean tuber number of ranging from 22.33 to 28.33.

With regard to the number of tubers per kg, the variety Sree Dhara, Nidhi and CTCRI line-74 performed equally well as they required a minimum number of tubers of 85.00, 91.00 and 93.67 respectively for making one kg. CTCRI lines 64 and 79 recorded 94 and 100.33 tubers per kg respectively and these two were statistically on par. The performance of Vellanikkara accessions (TC-9 and M-131), CTCRI lines (76 and 71) and the susceptible check Palappoor local was on par in the number of tubers per kg giving mean number of 105.67, 109.00, 107.00, 109.00 and 110.00 respectively.

Among the varieties/lines/accessions, the performance of variety Sree Dhara was statistically on par with variety Nidhi, CTCRI lines 74 and 64 giving mean tuber size of 17.50, 16.00, 16.00 and 15.50 cm respectively. There was no statistically significant variation in the size of tubers among CTCRI lines *viz.* 76 (14.33 cm), 71 (14.17 cm) and Vellanikkara accessions M-131 (13.83 cm) and TC-9 (12.67 cm) compared to the susceptible check, Palapoor local (12.00 cm).

Regarding the total weight of tubers per plant the performance of variety Sree Dhara (550.00 g) was statistically on par with variety Nidhi

Plate 5. Reaction of different varieties / lines / accessions of *S. rotundifolius* against *M. incognita* on shoot and root system

(521.67g). The same trend was observed in marketable weight of tubers per plant also with 446.67 and 410.00 g respectively. The next best one, CTCRI-74 recorded total tuber weight of 480g and marketable tuber weight of 390g respectively. The performance of CTCRI lines 64, 79, 76, 71 and Vellanikkara accession M-131 was on par in the case of weight of marketable tubers per plant whereas CTCRI line 76 and Vellanikkara accession M-131 was on par and inferior to CTCRI lines 64 and 79 in total weight of tubers per plant. There was no statistically significant variation between CTCRI line-71 (336.67 g), Vellanikkara accession TC-9 (330.00 g) and susceptible check, Palappoor local (311.67 g) in the total weight of tubers per plant whereas CTCRI line-71 (271.67) performed better than the susceptible check (223.33 g) in the marketable weight of tubers per plant (Plate 5).

In the case of edible portion (E.P.) weight of tubers per plant, the performance of variety Sree Dhara (346.67 g) was statistically on par with Nidhi (346.67g), while CTCRI line-74 was on par with CTCRI line-64 and 79 showing mean tuber weight of 253.33, 230.00 and 230.00 g respectively. CTCRI lines (76 and 71), Vellanikkara accessions (TC-9 and M-131) and susceptible check, Palappoor local exhibited no significant difference in performance with mean E.P weight ranging from 200.00 to 213.33g.

4.3.3 Nematode population characteristics

Data on reaction of varieties/lines/accessions of *S. rotundifolius* to *M. incognita* in terms of nematode population characteristics is presented in Tables 15 and 16.

Nematode Population in Soil

With respect to the nematode population in soil, at two MAP the lowest number of larvae was recorded in variety Sree Dhara (229.33 per 250 g soil) and it was significantly lesser to all other varieties, lines and

Table 15 Reaction of different varieties / lines / accessions of *S. rotundifolius* against *M. incognita* population characteristics at the time of harvest (mean of three replications)

Treatments	Nematode population in soil (250 g)			Nematode population in		Number of Root-knot in 5 g root	Root-knot index	Reaction
	2 MAP	4 MAP	5 MAP	Root (5 g)	Tuber (10 g)			
CTCRI line – 74	290.67 (17.08)	222.33 (14.94)	276.67 (16.66)	58.33 (7.70)	78.00 (8.86)	23.00 (4.89)	1.67	Moderately resistant
CTCRI line – 64	326.00 (18.08)	279.33 (16.74)	282.33 (16.83)	67.67 (8.28)	83.67 (9.20)	31.00 (5.65)	2.00	Moderately resistant
CTCRI line – 79	338.33 (18.42)	268.33 (16.41)	295.33 (17.21)	76.67 (8.81)	110.00 (10.53)	44.33 (6.73)	2.00	Moderately resistant
CTCRI line – 76	353.33 (18.82)	300.00 (17.35)	313.33 (17.73)	95.33 (9.81)	141.67 (11.94)	49.00 (7.06)	2.33	Moderately resistant
Sree Dhara	229.33 (15.18)	170.67 (13.10)	221.67 (14.92)	40.00 (6.40)	16.67 (4.18)	8.33 (3.05)	1.00	Resistant
CTCRI line – 71	373.00 (19.34)	337.67 (18.40)	352.00 (18.79)	120.67 (11.02)	162.33 (12.78)	61.00 (7.87)	3.00	Moderately susceptible
Vellanikkara accession – TC 9	391.67 (19.82)	340.00 (18.62)	384.67 (19.64)	152.67 (12.40)	191.00 (13.86)	70.00 (8.43)	3.00	Moderately susceptible
Vellanikkara accession – M 131	381.67 (19.56)	346.00 (18.47)	367.67 (19.20)	105.00 (10.29)	177.00 (13.34)	64.00 (8.06)	3.00	Moderately susceptible
Nidhi	240.67 (15.54)	200.67 (14.20)	228.33 (15.14)	55.33 (7.50)	26.67 (5.25)	14.67 (3.93)	1.00	Resistant
Palappoor local	409.33 (20.26)	365.67 (19.15)	391.67 (19.82)	181.67 (13.51)	206.00 (14.38)	77.67 (8.87)	3.67	Moderately susceptible
CD (0.05)	(0.32)	(0.54)	(0.32)	(0.57)	(0.50)	(0.55)	-	-

Figures in parenthesis are after $\sqrt{x+1}$ transformation

accessions. The performance of variety Nidhi, CTCRI line 74, 64, 79 and 76 was statistically on par in reducing the nematode multiplication recording 240.67 to 353.33 *M. incognita* juveniles per 250g soil. The Vellanikkara accession M-131 performed as equally well as CTCRI line-71 and Vellanikkara accession TC-9 showing significant superiority over the susceptible check, Palappoor local (409.33) with nematode population of 381.67, 373.00 and 391.67 respectively.

At four MAP, variety Sree Dhara recorded minimum *M. incognita* population in soil (170.67 per 250g soil) and performance of variety Nidhi and CTCRI line 74 was statistically independent with mean larval population of 200.67 and 222.33 per 250g soil respectively. CTCRI line-79 and 64 performed equally well showing 268.33 and 279.33 larvae per 250 g soil respectively. CTCRI lines (76 and 71) and Vellanikkara accession M-131 showed significant superiority over the susceptible check, Palappoor local (365.67) and Vellanikkara accession TC-9 (340.00) in reducing the nematode multiplication with mean nematode population ranging from 300.00 to 346.00.

At five MAP, the performance of variety Sree Dhara was statistically on par with Nidhi giving 221.67 and 228.33 larvae per 250g soil respectively. CTCRI line 74 (222.33 larvae per 250 g soil) showed statistically the same effect as that of CTCRI line-64 (279.33 larvae per 250 g soil) while CTCRI line 79 was statistically on par with CTCRI line-76 giving mean number of larvae of 295.33 and 313.33 per 250g soil respectively. CTCRI line 71 (352.00) and Vellanikkara accession M-131 (367.67) significantly reduced nematode multiplication at the root zone compared to Vellanikkara accession TC-9 (384.67) and susceptible check Palappoor local (391.67).

Nematode Population in Root

Regarding the nematode population in the root, variety Sree Dhara differed significantly from other varieties/lines / accessions recording the least number of larvae (40.00 per five g root). Variety Nidhi and CTCRI

line-74 performed equally well with mean larval population of 55.33 and 58.33 per five g root respectively. The performance of CTCRI lines 64 and 79 was on par recording mean larval population of 67.67 and 76.67 respectively. As similar trend was exhibited by CTCRI line- 76 and Vellanikkara accession M-131 with mean larval numbers of 95.33 and 105.00 per five g root respectively. The performance of CTCRI line-71 and Vellanikkara accession TC-9 was statistically independent and these two showed significant superiority over the susceptible check, Palappoor local (181.67) in reducing the larval multiplication in root with mean larval population of 120.67 and 152.67 respectively.

Nematode Population in Tuber

In the case of nematode population in tuber, the lowest number of larvae was recorded by variety Sree Dhara (16.67 per 10 g tuber). It differed significantly from all other varieties/lines/accessions. The performance of variety Nidhi, CTCRI lines (74, 64, 79, 76 and 71) and Vellanikkara accessions (TC-9 and M-131) was independent giving mean larval population to the tune of 26.67 to 191 per 10 g tuber. These varieties/lines/accessions showed significant superiority over the susceptible check, Palappoor local (206 larvae per 10g tuber) in reducing the nematode multiplication in tuber.

Root-knot count and Root knot index

The results on root-knot count revealed that all varieties/ lines /accessions showed significant superiority over the susceptible check, Palappoor local except Vellanikkara accession TC-9. The lowest mean gall number of 8.33 per five g root was recorded by variety Sree Dhara with least gall index of one. The variety Nidhi (14.67 per five g root) also recorded mean gall index of one. CTCRI lines-74 and 64 recorded mean root-knot count of 23.00 and 31.00 per five g root respectively. The mean root-knot index in these two lines was 1.67 and 2.00 respectively. The performance of all these four varieties/lines was

statistically independent and significantly superior to the susceptible check, Palappoor local with mean root-knot count of 77.67 and root-knot index of 3.67. CTCRI lines 79 and76 were statistically on par and recorded mean root-knot count of 44.33 and 49.00 per five g root respectively. CTCRI line 71 and Vellanikkara accession M-131 with mean root-knot count of 61.00 and 64.00 per five g root were statistically on par and showed significant superiority over the susceptible check, Palappoor local and Vellanikkara accession TC-9 (70.00 root-knots per five g). The above three lines and one accession recorded mean root-knot index of 2.00, 2.33, 3.00 and 3.00 respectively. The susceptible check, Palappor local recorded mean root-knot index of 3.67.

Reaction of varieties/ lines/ accessions

Based on root-knot index, Sree Dhara and Nidhi showed resistant reaction. CTCRI lines 64,79 and 76 were categorized as moderately resistant ones. CTCRI-71,Vellanikkara accession-M-131 and Palappoor local were categorized under moderately susceptible.

Number of Females

Minimum number of females per root was recorded in variety Sree Dhara (7.67 per five g root) and it showed significant superiority over the rest of varieties/lines/accessions. Variety Nidhi and CTCRI line-74 were also statistically independent in reaction with mean number of females of 13.00 and 23.00 per five g root respectively. CTCRI line-79 performed as equally well as CTCRI lines 64 and 76 showing mean number of 36.67 and 48.00 females respectively. The performance of CTCRI line 71 (62.67 females per five g root) and Vellanikkara accession M-131 (65.00 females per five g root) was statistically on par in reducing the production of females in coleus. There was no statistically significant variation between Vellanikkara accession TC-9 (77.33) and susceptible check, Palappoor local (84.67) in reducing the number of females.

Table 16. Reaction of different varieties / lines / accessions of *S. rotundifolius* against *M. incognita* population characteristics at the time of harvest (mean of three replications)

Treatments	Number of females in 5 g root	Number of egg masses in 5 g root	Number of eggs per egg mass
CTCRI line – 74	23.00 (4.89)	12.33 (3.64)	203.33 (14.28)
CTCRI line – 64	36.67 (6.13)	20.00 (4.58)	266.67 (16.35)
CTCRI line – 79	41.33 (6.49)	27.67 (5.35)	371.67 (19.30)
CTCRI line – 76	48.00 (6.99)	31.67 (5.71)	400.00 (20.02)
Sree Dhara	7.67 (2.92)	1.67 (1.58)	56.33 (7.56)
CTCRI line – 71	62.67 (7.98)	35.00 (6.00)	520.67 (22.84)
Vellanikkara accession – TC 9	77.33 (8.85)	44.33 (6.73)	603.33 (24.58)
Vellanikkara accession – M 131	65.00 (8.12)	36.67 (6.13)	531.67 (23.08)
Nidhi	13.00 (3.71)	5.67 (2.56)	132.33 (11.54)
Palappoor local	84.67 (9.25)	49.00 (7.07)	641.67 (25.35)
CD (0.05)	(0.62)	(0.52)	(0.78)

Figures in parenthesis are after $\sqrt{x + 1}$ transformation

Number of Egg masses

With regard to the number of egg masses per root, lowest number was recorded by variety Sree Dhara (1.67 per five g root). The reaction of variety Nidhi, CTCRI lines 74 and 64 was statistically independent with mean number of 5.67, 12.33 and 20.00 egg masses per five g root respectively. The performance of CTCRI line-76 (31.67) was statistically on par with CTCRI line 79 (27.67 egg masses per five g root) and CTCRI line-71 (35.00 egg masses per five g root). Vellanikkara accession M-131 showed significant superiority over Vellanikkara accession TC-9 and susceptible check, Palappoor local with mean number of 36.67 egg masses per root.

Number of eggs per egg mass

In the case of average number of eggs per egg mass, the lowest was recorded by variety Sree Dhara (203.33 per five g root). The variety Nidhi, CTCRI line-74 and 64 also showed statistically significant variation in production of eggs per egg mass. The reaction of CTCRI lines 79 and 76 was statistically on par with mean number of 371.67 and 400.00 respectively. CTCRI line-71 and Vellanikkara accession M-131 showed significant superiority over Vellanikkara accession TC-9 and susceptible check, Palappoor local with mean number of eggs per egg mass being 520.67 and 531.67 respectively.

4.3.4 Quality Parameters of Tubers

The changes in protein, starch, sugar and crude fibre content of tubers of selected varieties based on yield attributes are presented in Table 17.

Protein

In the case of protein content, the performance of Sree Dhara was statistically on par with local check, Palappor local giving values of 8.56 and 8.73 g respectively. Variety Nidhi, CTCRI lines 74, 64 and 79

Table 17. Variation in the chemical constituents of tubers obtained from selected varieties/lines/accessions of *S. rotundifolius* after harvest (mean of three replications)

Treatments	Protein (g / 100 g dry weight of tuber)	Percentage decrease of protein over check	Starch (g / 100 g dry weight of tuber)	Percentage increase of starch over check	Sugar (g / 100 g dry weight of tuber)	Percentage increase of sugar over check	Crude fibre (g / 100 g dry weight of tuber)	Percentage change of crude fibre over check
CTCRI line – 74	8.07	7.56	17.35	14.90	3.20	25.98	1.09	-7.63
CTCRI line – 64	8.05	7.79	17.47	15.70	2.95	16.14	1.27	+7.63
CTCRI line – 79	7.88	9.74	17.67	17.02	3.32	30.31	1.18	-
Sree Dhara	8.56	1.95	18.25	20.86	3.61	42.13	1.40	+18.64
Nidhi	8.18	6.30	17.97	19.00	3.46	36.22	1.05	-11.01
Palappoor local (Check)	8.73	-	15.10	-	2.54	-	1.18	-
CD (0.05)	0.21	-	0.58	-	0.16	-	0.38	-

recorded mean protein content of 8.18, 8.07, 8.05 and 7.88 g per 100 g dry weight of tuber respectively.

Starch

Regarding the starch content, the performance of variety Sree Dhara, Nidhi and CTCRI line 79 was on par showing 17.97 and 17.67 g per 100 g dry weight respectively. CTCRI line-64 and 74 recorded mean starch content of 17.47 and 17.35 g per 100 g dry weight of tuber respectively.

Sugar

Variety Sree Dhara and Nidhi performed significantly superior to the CTCRI lines 79, 74, 64 and Palappor local in sugar content, the values being 3.61, 3.46, 3.32, 3.20, 2.95 and 2.54 g per 100 g dry weight of tuber respectively.

Crude Fibre

Regarding the crude fibre content, the performance of varieties Sree Dhara, Nidhi, CTCRI lines 74, 64, 79 and Palappoor local was statistically on par with 1.05 to 1.27 g per 100 g dry weight of tuber.

4.4 FIELD EXPERIMENTS ON MANAGEMENT OF *M. INCOGNITA*

4.4.1 Under Nursery Condition

The effect of different nursery treatments *viz.*, soil solarization with 150 guage LDPE film for 15 days, hot water treatment of tubers, soil application of bioagents (*P. lilacinus, B. macerans, P. chlamydosporia*) was compared with recommended organic amendment, neem cake and chemical, carbosulfan. The effect of treatments was assessed in terms of improvement in biometric characters and reduction in population of nematodes. The results are presented in Tables 18 and 19.

4.4.1.1 Biometric Characters

There was statistically significant variation in biometric characters among plants grown under nursery condition with different treatments. The results are presented in Table 18.

Table 18. Effect of different treatments in nursery on the biometric characters of *S. rotundifolius* (30 days after planting) (mean of three replications)

Treatments	Plant height (cm)	Percentage increase over untreated	Number of leaves	Percentage increase over untreated	Number of branches	Percentage increase over untreated	Plant spread (cm)	Percentage increase over untreated	Leaf area index	Percentage increase over untreated
S.S. (150 LDPE for 15 days)	31.00	85.96	227.00	79.21	11.33	88.83	56.33	83.66	3.17	81.14
HWT (50°C for 20 minutes)	27.33	63.95	201.67	59.21	9.67	61.16	46.00	51.61	2.13	21.71
P.l. (30 g m^{-2})	30.00	79.96	212.33	67.62	11.00	83.33	52.00	69.55	2.97	69.71
B.m. (30 g m^{-2})	28.67	71.99	211.33	66.84	10.00	66.66	50.33	64.10	2.82	61.14
B.m. (30 g m^{-2}) (1 MAP)	27.00	61.97	206.67	63.16	9.33	55.50	45.67	48.91	2.71	54.86
P.chl. (30 g m^{-2})	26.67	59.99	184.67	45.79	9.00	50.00	42.67	39.13	2.03	16.00
NC (100 g m^{-2})	24.67	47.99	182.00	43.68	8.67	44.50	39.00	27.16	1.98	13.14
Carb (1.5 kg ai ha^{-1})	28.33	69.95	209.33	65.26	10.00	66.66	46.67	52.17	2.55	45.71
Untreated	16.67	-	126.67	-	6.00	-	30.67	-	1.75	-
CD (0.05)	3.81	-	13.10	-	1.04	-	2.35	-	0.37	-

S.S. - Soil solarization, HWT - Hot water treatment, P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans*, P.chl – *Pochonia chlamydosporia*, NC – Neem cake, Carb – Carbosulfan

Plant height

All the treatments showed significant increase in height of plants compared to the untreated (16.67 cm). Among the effective treatments, highest significant increase in height of plants (31.00 cm) was observed in solarized plots and it was on par with *P. lilacinus* (30.00 cm), *B. macerans* at the time of planting (28.67 cm), carbosulfan (28.33 cm) and hot water treatments of tubers before planting (27.33 cm). The percentage increase in plant height in the above treatments ranged from 63.95 to 85.96. The effect of *B. macerans* application at one month after planting (MAP), soil application of *P. chlamydosporia* and neemcake at the time of planting of tubers was on par and inferior to the above treatments with mean plant heights of 27.00, 26.67 and 24.67 cm respectively.

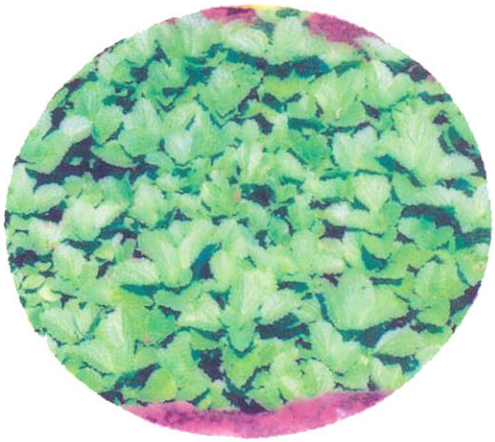
Number of Leaves

All the treatments increased the number of leaves significantly when compared with the untreated (126.67). Among the treatments solarization, *P. lilacinus*, *B. macerans* at planting, carbosulfan and *B. macerans* at one MAP and hot water treatment recorded mean leaf number of 227.00, 212.33, 211.33, 209.33, 206.67 and 201.67 respectively and these treatments were statistically on par and superior to all the other treatments. The percentage increase in leaf number in the above treatments ranged from 59.21 to 79.21 over the untreated. The effect of *P. chlamydosporia* (184.67) and neemcake (182.00) was statistically on par showing significant superiority over the untreated. The percentage increase in the number of leaves in these two treatments was 45.79 and 43.68 respectively.

Number of Branches

All the treatments showed significant superiority over the untreated (6.00) in increasing the number of branches. Significantly higher number of branches was observed in solarization and *P. lilacinus* treatments, the

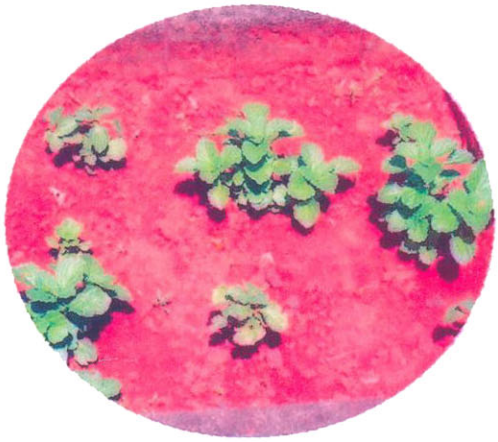
Solarization



Paecilomyces lilacinus

Bacillus macerans

Carbosulfan



Untreated

Plate 6. Effect of various treatments in the nursery on the establishment of *S. rotundifolius* plants 20 days after planting

mean number of branches being 11.33 and 11.00 respectively. The percentage increase in the above two treatments over untreated was 88.83 and 83.33 respectively. The effect of *B. macerans* (10.00), carbosulfan (10.00), hot water treatment (9.67), *B. macerans* (one MAP) (9.33) and *P. chlamydosporia* (9.00) was statistically on par giving 50.00 to 66.66 per cent increase over the untreated. Neemcake (8.67) treatment also showed statistically significant increase (44.50 per cent) in number of branches.

Plant Spread

All the treatments significantly improved the plant spread compared to the untreated (30.67 cm). Soil solarization showed statistically significant superiority over all other treatments and untreated (83.66 per cent increase) with a mean plant spread of 56.33 cm. The effect of the treatments *viz.*, *P. lilacinus* and *B. macerans* was statistically on par showing mean plant spread of 52 and 50.33 cm respectively. The effect of carbosulfan, hot water treatment and *B. macerans* at one MAP was statistically on par and superior to *P. chlamydosporia* (42.67 cm) and neemcake (39.00 cm) treatments with mean plant spread ranging from 45.67 to 46.67 cm (Plate 6).

Leaf Area Index

There was statistically significant variation in the leaf area index of *S. rotundifolius* plants due to different treatments in nursery compared to the untreated (1.75). The effect of soil solarization, *P. lilacinus* and *B. macerans* at planting was statistically on par giving mean leaf area index of 3.17, 2.97 and 2.82 respectively. The percentage increase in leaf area over the untreated in the these three treatments ranged from 61.14 to 81.14. The treatments, *B. macerans* (one MAP) and carbosulfan were statistically on par with mean leaf area index of 2.71 and 2.55 respectively. The effect of hot water treatment (2.13), *P. chlamydosporia* (2.03) and neemcake (1.98) was statistically on par and significantly inferior to the above treatments.

Table 19. Effect of different treatments in nursery on nematode population characteristics of *M. incognita* in *S. rotundifolius* (30 days after planting) (mean of three replications)

Treatments	Nematode population in 250 g soil	Nematode population in 5 g root			Root-knot index	Number of egg masses in 5 g root	Number of eggs per egg mass
		Number of larvae	Number of females	Number of root-knots			
S.S. (150 LDPE for 15 days)	15.00 (3.99)	12.33 (3.64)	10.00 (3.26)	6.33 (2.60)	2	7.33 (2.85)	23.33 (4.85)
HWT (50°C for 20 minutes)	55.67 (7.52)	35.30 (6.02)	25.00 (5.09)	16.67 (4.18)	4	25.33 (5.13)	130.00 (11.42)
P.l. (30 g m^{-2})	28.33 (5.38)	19.00 (4.39)	12.33 (3.64)	10.00 (3.26)	2	12.33 (3.64)	41.67 (6.53)
B.m. (30 g m^{-2})	30.67 (5.62)	22.33 (4.79)	15.00 (3.99)	11.33 (3.51)	3	16.33 (4.13)	25.67 (5.15)
B.m. (30 g m^{-2}) (1 MAP)	60.00 (7.80)	22.33 (4.82)	19.33 (4.49)	14.33 (3.91)	3	18.33 (4.39)	75.67 (8.75)
P.chl. (30 g m^{-2})	66.67 (8.22)	39.00 (6.28)	31.33 (15.67)	21.33 (4.72)	5	31.67 (5.71)	163.33 (12.80)
NC (100 g m^{-2})	77.67 (8.87)	43.67 (6.63)	39.00 (6.32)	22.33 (4.82)	5	39.00 (6.32)	200.00 (14.18)
Carb (1.5 kg ai ha^{-1})	39.33 (6.32)	32.67 (5.78)	20.00 (4.58)	12.00 (3.60)	3	22.33 (4.83)	123.33 (11.11)
Untreated	120.00 (10.99)	133.33 (11.58)	76.67 (8.81)	53.33 (7.36)	5	47.67 (6.98)	300.00 (16.31)
CD (0.05)	(0.74)	(0.84)	(0.76)	(0.83)		(0.68)	(1.55)

S.S. - Soil solarization, HWT - Hot water treatment, P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans*, P.chl – *Pochonia chlamydosporia*, NC – Neem cake, Carb – Carbosulfan

Figures in parenthesis are after $\sqrt{x+1}$ transformation

4.4.1.2 Nematode population characteristics

The results presented in Table 19 showed statistically significant reduction in the population characteristics of *M. incognita* in different treatments in nursery compared to untreated except nematode population in root and number of egg masses per root. The initial population ranged from 148 to 160 per 250 g soil sample.

Nematode Population in Soil

The population of *M. incognita* was the lowest in solarized plots (15/250 g soil) and was significantly superior to all the other treatments in suppressing *M. incognita* in soil. The treatments *P. lilacinus* and *B. macerans* recorded 28.33 and 30.67 *M. incognita* per 250 g soil respectively and the effect was statistically on par and superior to the recommended chemical carbosulfan. Carbosulfan recorded a mean population of 39.33 *M. incognita* per 250 g soil and it was significantly superior to all the other treatments and untreated control (120 per 250 g soil). The effect of hot water treatment, *B. macerans* (one MAP) and *P. chlamydosporia* (55.67, 60.00 and 66.67 *M. incognita* per 250 g soil respectively) was statistically on par and significantly superior to neemcake (77.67 per 250 g soil) and untreated control. Thus solarization and application of *B. macerans* and *P. lilacinus* @ 30 g m^{-2} were the best treatments and their effect was superior to the chemical in reducing the nematodes initially in soil.

Nematode population in root

In the case of nematode population in root, statistically similar effect was obtained in nursery soil solarization (12.33) and *P. lilacinus* application (19.00) and these two were significantly superior to all the other treatments. The effect of *B. macerans* at planting (22.33) and *B. macerans* (one MAP) (22.33) was statistically on par in suppressing the

nematode population in roots. The treatments carbosulfan (32.67), hot water (35.30) and *P. chlamydosporia* (39.00) were statistically on par and significantly superior to neem cake (43.67) and untreated control (133.33).

Number of Females

There was statistically significant variation in the number of females between different treatments compared to the untreated. The effect of solarization (10 per five g root) was statistically on par with *P. lilacinus* (12.33 per five g root) and *B. macerans* at planting (15.00 per five g root). The effect of *B. macerans* (one MAP) (19.33) was statistically on par with carbosulfan (20.00) and hot water treatment (25.00). The effect of *P. chlamydosporia* and neemcake was statistically on par showing mean number of females of 31.33 and 39.00 per five g root respectively.

Root-knot Count

The data relating to root-knot count showed the effectiveness of various nursery treatments in reducing the gall formation which ranged from 6.33 to 22.33 in treated plants as against 53.33 in untreated. Among the treatments, solarization (6.33 per five g root) and *P. lilacinus* (10.00 per five g root) showed significant superiority over all other treatments in reducing the root-knot count. These two treatments were statistically on par. Nursery treatment with *B. macerans* at the time of planting, *B. macerans* (one MAP) and hot water treatment was as effective as the chemical carbosulfan in reducing gall formation with mean root-knot count ranging from 11.33 to 16.67 per five g root. The effect of *P. chlamydosporia* (21.33) and neem cake (22.33) was statistically on par and significantly superior to the untreated in reducing the root-knots.

The gall index estimated was the lowest in solarization of nursery and *P. lilacinus* with gall index of two and the effect of these treatments was better than the chemical treatment carbosulfan. However application

of *B. macerans* at the time of planting and one MAP was equivalent to the chemical and recorded the same root-knot index of three.

Number of Egg Masses per Root

The lowest number of egg masses was recorded in nursery solarization (7.33) and it was significantly superior to all other treatments and untreated (46.67). The effect of *P. lilacinus* (12.33) and *B. macerans* basal application (16.33) in nursery was statistically on par and these two were better than the chemical, carbosulfan (22.33). However the application of *B. macerans* (one MAP) in nursery (18.33) was statistically on par with carbosulfan. Statistically the same effect was observed in hot water and *P. chlamydosporia* treatments with mean number of egg masses of 25.33 and 31.67 respectively and these two treatments showed significant superiority over neem cake (39.00) and untreated (47.67).

Number of Eggs per Egg Mass

Significantly lower number of eggs per egg masses was found in coleus roots collected from solarized nursery (23.33) and it was statistically on par with *B. macerans* at the time of planting (25.67). The treatments, *P. lilacinus* (41.67) and *B. macerans* (one MAP) (75.67) were significantly different in reducing the number of eggs per egg mass and these treatments showed significant superiority over the chemical, carbosulfan (123.33) which was on par with hot water treatment (130.00). *P. chlamydosporia* (163.33) was statistically on par with neem cake (200.00) and significantly reduced the average number of eggs per egg mass compared to untreated (300.00).

4.4.2 Under Main Field Condition

The effect of different treatments on the management of *M. incognita* infesting coleus, *S. rotundifolius* were evaluated in sick plots having *M. incognita* infestation (180 to 230 per 250 g soil). The effect of bioagents (*P. lilacinus, B. macerans* and *P. chlamydosporia*) and the

recommended organic amendment, neem cake was evaluated singly and in combinations in main field in terms of improvement in biometric characters, yield and reduction in population of nematodes at different intervals and quality parameters (starch, sugar, protein and crude fibre content of the tubers). The results on the above are presented in Tables 20 to 26.

4.4.2.1 Biometric Characters

All the treatments showed statistically significant variation in plant height, number of leaves, number of branches, plant spread and leaf area index at different monthly intervals and the results are presented in Tables 20 to 22.

Plant Height

The results presented in Table 20 showed the effect of different main field treatments on the mean plant height and number of leaves of *S. rotundifolius* at different intervals. All the treatments were significantly superior to the untreated in improving plant height and leaf production except the observations recorded at two and five months after treatment.

In the case of height of *S. rotundifolius* recorded, the effect of *P. lilacinus* + neem cake treatment was statistically on par with *P. lilacinus* + *B. macerans* with mean plant height of 26.00 and 25.67 cm respectively at one month after treatment (MAT). These two treatments showed significant superiority over the chemical, carbosulfan (22.67 cm). The effect of the treatments, *B. macerans* + neem cake, *P. lilacinus* + *P. chlamydosporia*, *P. lilacinus*, *B. macerans* (one MAP), *B. macerans* at the time of planting and *P. chlamydosporia* + *B. macerans* was statistically on par and as good as the chemical giving mean plant height of 21.33, 21.00, 21.00, 20.67, 20.67 and 20.33 cm respectively. *P. chlamydosporia* (19.67 cm), *P. chlamydosporia* + neem cake (19.67 cm) and

Table 20. Effect of different treatments in main field on the biometric characters of *S. rotundifolius* at different intervals (mean of three replications)

Treatments	Biometric characters observed at monthly intervals									
	Height of plant (cm)					Number of leaves				
	1 MAT	2 MAT	3 MAT	4 MAT	5 MAT	1 MAT	2 MAT	3 MAT	4 MAT	5 MAT
P.l. (30 g m^{-2})	21.00	26.67	38.00	52.33	53.67	366.67	688.33	923.33	806.67	523.33
B.m. (30 g m^{-2})	20.67	25.00	37.00	50.33	53.00	345.33	476.67	907.33	803.33	517.67
B.m. (30 g m^{-2}) (1MAP)	20.67	24.33	35.33	50.00	52.67	345.00	666.67	870.67	756.67	493.33
P.chl. (30 g m^{-2})	19.67	22.67	30.00	40.00	48.33	321.33	628.33	810.67	726.00	433.33
NC (100 g m^{-2})	19.33	22.67	30.00	40.00	43.33	326.67	610.00	800.00	703.33	400.00
P.l. (15 g m^{-2}) + B.m. (15 g m^{-2})	25.67	30.00	45.33	59.33	61.67	460.00	750.00	976.00	860.00	578.33
P.l. (15 g m^{-2}) + P.chl. (15 g m^{-2})	21.00	27.67	41.67	55.00	60.00	425.67	731.67	961.67	813.33	553.33
P.chl. (15 g m^{-2}) + B.m. (15 g m^{-2})	20.33	23.33	32.33	46.67	50.33	342.33	646.67	864.00	753.33	473.33
P.l. (15 g m^{-2}) + NC (100 g m^{-2})	26.00	31.00	46.67	60.67	63.67	480.67	760.00	998.33	870.00	600.00
B.m. (15 g m^{-2}) + NC (100 g m^{-2})	21.33	27.00	38.67	54.00	57.67	380.00	708.33	953.33	810.00	526.67
P.chl. (15 g m^{-2}) + NC (100 g m^{-2})	19.67	23.00	32.11	43.33	49.67	336.67	640.00	859.00	726.67	433.33
Carb. (1.5 kg ai ha^{-1})	22.67	29.00	45.00	59.00	60.67	433.33	723.33	971.67	837.33	566.67
Untreated	15.67	18.33	25.00	37.00	39.33	291.67	462.33	673.33	610.00	366.67
CD (0.05)	2.94	3.23	3.67	4.27	5.42	28.71	168.64	20.99	33.13	28.38

P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans,* P.chl – *Pochonia chlamydosporia*, NC – Neem cake, Carb – Carbosulfan
MAT – Months after treatment

neem cake (19.33 cm) treatments also showed statistically significant increase in plant height of *S. rotundifolius* over the untreated (15.67 cm).

When plant height was recorded two MAT the combination of *P. lilacinus* + neem cake (31.00 cm) found to be statistically on par with *P. lilacinus* + *B. macerans* (30.00 cm) and carbosulfan (29.00 cm) revealing that these two treatments were equally effective to the chemical carbosulfan. The treatments, *P. lilacinus* + *P. chlamydosporia*, *B. macerans* + neem cake, *P. lilacinus* and *B. macerans* were statistically on par with mean plant height of 27.67, 27.00, 26.67 and 25.00 cm respectively. The other treatments in the order of effectiveness were *B. macerans* (one MAP), *P. chlamydosporia* + *B. macerans*, *P. chlamydosporia* + neem cake, *P. chlamydosporia* and neem cake giving a plant height of above 22.00 cm. The effect of these treatments was statistically on par and significantly superior to the untreated (18.33 cm).

During the third month after the treatment, significantly higher mean plant height was recorded by *P. lilacinus* + neem cake (46.67 cm) followed by *P. lilacinus* + *B. macerans* (45.33 cm) and carbosulfan (45.00 cm). Thus the effect of these treatments was on par with the chemical. The effect of the treatments, *P. lilacinus* + *P. chlamydosporia*, *B. macerans* + neem cake and *P. lilacinus* was statistically on par and significantly superior to all the other treatments with plant height ranging from 38.00 to 41.67 cm. *B. macerans* at the time of planting and *B. macerans* (one MAP) were statistically on par with mean plant height of 37.00 and 35.33 cm respectively revealing that there was no significant impact on the time of application. There was no statistically significant variation in the combined effect of *P. chlamydosporia* with *B. macerans* and neem cake over the individual application of *P. chlamydosporia* and neem cake alone giving mean plant height to the tune of 30.00 to 32.33 cm.

The effect of *P. lilacinus* + neem cake (60.67 cm) was statistically on par with *P. lilacinus* + *B. macerans* (59.33 cm) and carbosulfan (59.00 cm) at

four MAT. The effect of treatments, *P. lilacinus* + *P. chlamydosporia* (55.00 cm), *B. macerans* + neem cake (54.00 cm) and *P. lilacinus* alone (52.33 cm) was statistically on par and significantly inferior to the chemical in plant height. The treatments, *B. macerans* at the time of planting, *B. macerans* (one MAP) and *P. chlamydosporia* + *B. macerans* also showed statistically significant superiority over the other treatments and untreated with mean plant height of 50.33, 50.00, 46.67 cm respectively. Here also the result revealed that the time of application of *B. macerans* has no impact in improving the plant height. The effect of combined application of *P. chlamydosporia* with neem cake (43.33 cm) was statistically on par with *P. chlamydosporia* (40.00 cm) and neem cake alone (40.00 cm) treatments revealing that there was no added advantage in combining neem cake with *P. chlamydosporia.*

Among the treatments, *P. lilacinus* + neem cake (63.67 cm) was statistically on par with *P. lilacinus* + *B. macerans*, carbosulfan, *P. lilacinus* + *P. chlamydosporia* and *B. macerans* + neem cake treatments with mean plant height of 61.67, 60.67, 60.00 and 57.67 cm respectively at five MAT. This established the fact that the above four treatments were as effective as the chemical. The other treatments in the order of effectiveness were *P. lilacinus*, *B. macerans*, *B. macerans* (one MAP), *P. chlamydosporia* + *B. macerans*, *P. chlamydosporia* + neem cake and *P. chlamydosporia* giving mean plant height to the tune of 48.33 to 53.67 cm.

Number of Leaves

Significantly higher number of leaves was recorded in *P. lilacinus* + neem cake treatment (480.67) and it was statistically on par with *P. lilacinus* + *B. macerans* (460.00) at one MAT. These two treatments were statistically superior to all the other treatments including the chemical. Carbosulfan and *P. lilacinus* + *P. chlamydosporia* were statistically on par with mean leaf number of 433.33 and 425.67 respectively establishing that combination of *P. lilacinus* with

P. chlamydosporia was as effective as the chemical. The effect of *B. macerans* + neem cake (380.00) was statistically on par with *P. lilacinus* alone (366.67) while *B. macerans* at the time of planting was on par with *B. macerans* (one MAP), *P. chlamydosporia* + *B. macerans*, *P. chlamydosporia* + neem cake, neem cake and *P. chlamydosporia* alone giving 321.33 to 345.33 leaves per plant.

All the treatments except *P. chlamydosporia* (628.33), neem cake (610.00), *B. macerans* at the time of planting (476.67) significantly improved the number of leaves of *S. rotundifolius* at two months after treatment. The effect of *P. lilacinus* + neem cake (760.00) was found to be statistically on par with *P. lilacinus* + *B. macerans*, *P. lilacinus* + *P. chlamydosporia*, carbosulfan, *B. macerans* + neem cake, *P. lilacinus*, *B. macerans* (one MAP), *P. chlamydosporia* + *B. macerans* and *P. chlamydosporia* + neem cake treatments with mean leaf number more than 640.00. The chemical, carbosulfan was equally as effective as the above bioagents and combination of bioagent and organic amendment in improving the leaf production.

Regarding the improvement in leaf production of coleus plants recorded at three months after treatment, *P. lilacinus* + neem cake (998.33) established statistically significant superiority over the all other treatments including the chemical. The effect of treatments, *P. lilacinus* + *B. macerans*, carbosulfan and *P. lilacinus* + *P. chlamydosporia* were statistically on par giving mean leaf number of 976.00, 971.67 and 961.67 respectively. Thus these two treatments were as good as the chemical. *B. macerans* + neem cake treatment (810.00) also showed significant superiority over all the other treatments but inferior to the above three treatments and chemical (absolute check). *P. lilacinus* and *B. macerans* alone at the time of planting were statistically on par with number of leaves, 923.33 and 907.33 respectively. *B. macerans* (one MAP) was statistically on par with *P. chlamydosporia* + *B. macerans* and *P. chlamydosporia* + neem

cake, while *P. chlamydosporia* was on par with neem cake. The mean number of leaves in the above treatments ranged from 800.00 to 870.67.

Among the treatments, the effect of *P. lilacinus* + neem cake (870.00) was statistically on par with *P. lilacinus* + *B. macerans* (860.00) in increasing the number of leaves at four months after treatment. These treatments established significant superiority over the chemical, carbosulfan. The effect of treatments, carbosulfan (837.33), *P. lilacinus* + *P. chlamydosporia* (813.33), *B. macerans* + neem cake (810.00) and *P. lilacinus* alone (806.67) was statistically on par and significantly superior to all the other treatments revealing that the above three treatments were as effective as the chemical. The other treatments in the order of effectiveness were *B. macerans* at planting (803.33), *B. macerans* (one MAP) (756.67), *P. chlamydosporia* + *B. macerans* (753.33), *P. chlamydosporia* + neem cake (726.67) and *P. chlamydosporia* (726.00) and the effect of these were statistically on par. The organic amendment, neem cake alone also showed significant superiority over the untreated (610.00) giving mean leaf number of 703.33.

During the fifth month, the effect of the treatment combination *P. lilacinus* + neem cake (600.00) was statistically on par with *P. lilacinus* + *B. macerans* (578.33) establishing its superiority over the chemical, carbosulfan. The effect of carbosulfan (566.67) and *P. lilacinus* + *P. chlamydosporia* (553.33) was statistically on par revealing that this combination treatment was as effective as the chemical. The effect of other treatments were as follows. *B. macerans* + neem cake (526.67) was on par with *P. lilacinus* (523.33) and *B. macerans* (517.67). The treatments *B. macerans* (one MAP) and *P. chlamydosporia* + *B. macerans* were statistically on par with mean leaf number of 493.33 and 473.33 respectively. The effect of *P. chlamydosporia* + neem cake and *P. chlamydosporia* alone was statistically on par and recorded the same mean leaf number of 433.33. Neem cake also showed significant

superiority over the untreated (366.67) giving mean number of 400.00 leaves.

Number of Branches

All the treatments except neem cake showed statistically significant superiority in number of branches compared to the untreated at one, two and three MAT. Among the treatments, significantly higher number of branches was observed in *P. lilacinus* + neem cake (28.33). It was statistically on par with *P. lilacinus* + *B. macerans* (27.67), carbosulfan (26.33) and *P. lilacinus* + *P. chlamydosporia* (26.33) and the above three treatment combinations were as effective as the chemical. The other treatments *viz.*, *B. macerans* + neem cake, *P. lilacinus* and *B. macerans* were statistically on par with mean number of branches of 25.33, 24.67 and 23.67 respectively. The effect of *B. macerans* (one MAP) (22.00) was on par with *P. chlamydosporia* + neem cake (21.00), *P. chlamydosporia* + *B. macerans* (21.00) and *P. chlamydosporia* alone (20.00) and significantly superior to neem cake (19.00) and untreated control (17.00).. Thus it was evident that there was no added advantage in combining neem cake with *B. macerans* and *P. chlamydosporia.*

The number of branches under various main field treatments showed statistically significant variation at two MAT. All the treatments except neem cake (28.00) and *P. chlamydosporia* (29.67) significantly improved the number of branches compared to the untreated (27.33). The mean number of branches under different treatments varied from 27.33 to 46.33. *P. lilacinus* + neem cake (46.33) treatment showed statistically similar effect as that of *P. lilacinus* + *B. macerans* (44.33). The effect of the above treatments was significantly better than the chemical, carbosulfan. The effects of carbosulfan, *P. lilacinus* + *P. chlamydosporia*, *B. macerans* + neem cake, *P. lilacinus* and *B. macerans* alone were statistically on par with mean number of branches of 42.33, 39.00, 38.33, 38.00 and 37.33 respectively revealing that these treatments were as

Table 21. Effect of different treatments in the main field on the biometric characters of *S. rotundifolius* at different intervals (mean of three replications)

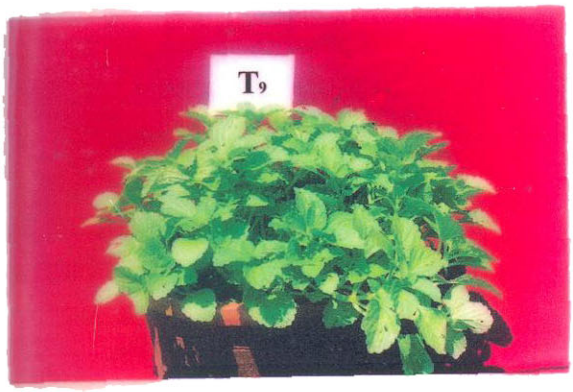
Treatments	Biometric characters observed at monthly intervals									
	Number of branches					Plant spread (cm)				
	1 MAT	2 MAT	3 MAT	4 MAT	5 MAT	1 MAT	2 MAT	3 MAT	4 MAT	5 MAT
P.l. (30 g m^{-2})	24.67	38.00	50.00	61.67	70.67	41.33	52.00	67.67	68.67	77.67
B.m. (30 g m^{-2})	23.67	37.33	53.33	58.33	67.67	40.33	51.33	65.67	67.67	77.33
B.m. (30 g m^{-2}) (1MAP)	22.00	36.00	47.33	57.33	64.00	39.00	50.33	64.67	66.00	77.00
P.chl. (30 g m^{-2})	20.00	29.67	44.67	50.00	61.00	34.67	46.67	61.00	60.67	64.00
NC (100 g m^{-2})	19.00	28.00	42.33	48.00	50.33	34.33	40.00	55.67	60.00	58.67
P.l. (15 g m^{-2}) + B.m. (15 g m^{-2})	27.67	44.33	68.67	64.00	80.67	48.00	54.00	70.67	72.67	84.67
P.l. (15 g m^{-2}) + P.chl. (15 g m^{-2})	26.33	39.00	62.67	62.33	68.00	42.33	52.67	69.00	72.00	81.67
P.chl. (15 g m^{-2}) + B.m. (15 g m^{-2})	21.00	32.67	45.00	52.33	65.00	37.67	48.33	62.00	65.67	74.67
P.l. (15 g m^{-2}) + NC (100 g m^{-2})	28.33	46.33	70.00	67.33	83.33	51.33	57.33	71.33	75.00	85.00
B.m. (15 g m^{-2}) + NC (100 g m^{-2})	25.33	38.33	61.00	62.00	72.33	42.00	52.33	68.00	70.00	79.33
P.chl. (15 g m^{-2}) + NC (100 g m^{-2})	21.00	31.67	44.67	51.00	62.33	37.33	47.67	61.67	65.33	70.00
Carb. (1.5 kg ai ha^{-1})	26.33	42.33	67.67	62.33	80.00	44.00	53.67	70.00	72.33	83.00
Untreated	17.00	27.33	40.00	42.33	47.67	30.00	34.33	36.33	43.33	52.33
CD (0.05)	2.41	2.95	4.17	5.21	10.19	4.72	4.12	5.45	4.95	4.03

P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans*, P.chl – *Pochonia chlamydosporia*, NC – Neem cake, Carb – Carbosulfan
MAT – Months after treatment

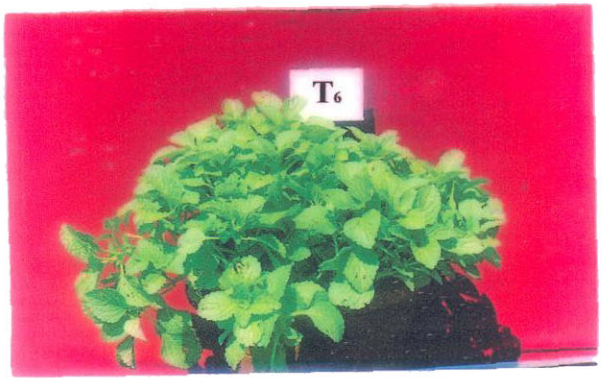
effective as the chemical, carbosulfan. The treatment, *P. chlamydosporia* + *B. macerans* (32.67) was significantly inferior to *B. macerans* (one MAP) (36.00) but was statistically on par with *P. chlamydosporia* + neem cake (31.67).

There was statistically significant variation in number of branches produced by coleus plants after the application of different treatments in the main field at three MAT. All the treatments were significantly superior to the untreated (40.00) except neem cake (42.33). *P. lilacinus* + neem cake treated plants produced significantly higher number of branches (70.00) and this treatment was on par with *P. lilacinus* + *B. macerans* (68.67) and carbosulfan (67.67). The effect of *P. lilacinus* + *P. chlamydosporia* (62.67) and *B. macerans* + neem cake (61.00) was statistically on par, but not as effective as the chemical and the above 5 treatments were significantly better than other treatments. The effect of *B. macerans* (53.33) was statistically on par with *P. lilacinus* (50.00). Treatments, *B. macerans* (one MAP), *P. chlamydosporia* + *B. macerans*, *P. chlamydosporia* and *P. chlamydosporia* + neem cake were statistically on par 47.33, 45.00, 44.67 and 44.67 branches respectively.

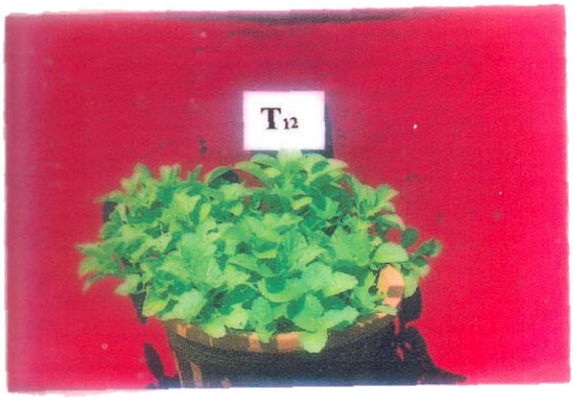
There was statistically significant variation in the number of branches of *S. rotundifolius* plants at four MAT compared to the untreated (42.33). *P. lilacinus* + neem cake combination recorded significantly higher number of branches (67.33) and it was statistically on par with *P. lilacinus* + *B. macerans*, *P. lilacinus* + *P. chlamydosporia* and carbosulfan giving mean branch number of 64.00, 62.33 and 62.33 respectively. Thus the above three treatments were as effective as the chemical, carbosulfan. *B. macerans* + neem cake treatment was significantly inferior to carbosulfan but was on par with *P. lilacinus*, *B. macerans* (at the time of planting) and *B. macerans* (one MAP) showing statistically significant superiority over all other treatments and untreated (42.33). The effect of the other treatments, *P. chlamydosporia* + *B. macerans*,



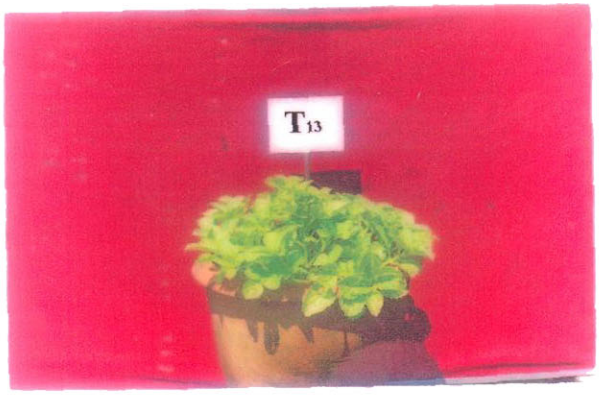
P. lilacinus + neem cake



P. lilacinus + *B. macerans*



Carbosulfan



Untreated

Plate 7. Effect of different treatment combinations in improving the biometric characters of *S. rotundifolius* plants compared to chemical and untreated

P. chlamydosporia + neem cake, *P. chlamydosporia* and neem cake alone were statistically on par giving 48.00 to 52.33 branches.

All the treatments showed statistically significant variation in number of branches compared to the untreated at five MAT. The effects of treatments, *P. lilacinus* + neem cake, *P. lilacinus* + *B. macerans* and carbosulfan were statistically on par, the values being 83.33, 80.67 and 80.00 respectively. These two treatments were as effective as the chemical. The other treatments in the order of effectiveness were *B. macerans* + neem cake, *P. lilacinus*, *P. lilacinus* + *P. chlamydosporia*, *B. macerans*, *P. chlamydosporia* + *B. macerans*, *B. macerans* (one MAP) and *P. chlamydosporia* + neem cake giving more than 62.33 branches. The effect of above treatments was statistically on par and significantly superior to *P. chlamydosporia* (61.00), neem cake (50.33) and untreated (47.67) (Table 21).

Plant Spread

There was statistically significant increase in plant spread compared to the untreated at one, two, three, four and five MAT. The plant spread recorded in *P. lilacinus* + neem cake treated plants (51.33 cm) was found to be statistically on par with *P. lilacinus* + *B. macerans* (48.00 cm) and showed significant superiority over all other treatments including chemical carbosulfan at one MAT. The treatments, *P. lilacinus* + *P. chlamydosporia* (42.33 cm), *B. macerans* + neem cake (42.00 cm), *P. lilacinus* (41.33 cm) and *B. macerans* at the time of planting (40.33 cm) were as equally effective as the chemical carbosulfan (44.00) in improving plant spread. The other treatments in the order of effectiveness were *B. macerans* (one MAP), *P. chlamydosporia* + *B. macerans*, *P. chlamydosporia* + neem cake, *P. chlamydosporia* and neem cake respectively with mean plant spread ranging from 34.33 to 39.00 cm. Here these treatments showed significant superiority over the untreated (30.00 cm) in improving plant spread though they were inferior to the chemical, carbosulfan (Plate 7).

Regarding the plant spread recorded two MAT, the effect of *P. lilacinus* + neem cake (57.33 cm) was statistically on par with *P. lilacinus* + *B. macerans* (54.00 cm) and carbosulfan (53.67 cm) treatments. The effects of treatments, *P. lilacinus* + *P. chlamydosporia*, *B. macerans* + neem cake, *P. lilacinus* and *B. macerans* at planting and *B. macerans* (one MAP) were statistically on par and inferior to the chemical with mean plant spread of 52.67, 52.33, 52.00, 51.33 and 50.33 cm respectively. *P. chlamydosporia* + *B. macerans* (48.33 cm) showed statistically the same effect as that of *P. chlamydosporia* + neem cake (53.67 cm) and *P. chlamydosporia* alone (46.67 cm) while *P. chlamydosporia* alone was on par with neem cake alone showing mean plant spread of 46.67 and 40.00 cm respectively. This revealed that there was no added advantage in combining neem cake or *B. macerans* with *P. chlamydosporia*.

At three MAT significantly higher plant spread was obtained in *P. lilacinus* + neem cake treatment and it was statistically on par with *P. lilacinus* + *B. macerans* (70.67 cm), carbosulfan (70.00 cm), *P. lilacinus* + *P. chlamydosporia* (69.00 cm), *B. macerans* + neem cake (68.00 cm) and *P. lilacinus* alone (67.67 cm) revealing that *P. lilacinus* alone and in combination with bioagents (*B. macerans* and *P. chlamydosporia*) and organic amendment (neem cake) as effective as chemical carbosulfan in improving plant spread. *B. macerans* at the time of planting (65.67 cm) was statistically on par with *B. macerans* (one MAP) (64.67 cm), *P. chlamydosporia* + *B. macerans* (62.00 cm), *P. chlamydosporia* + neem cake (65.33 cm) and *P. chlamydosporia* alone (60.67 cm). There was no significant impact on the time of application of *B. macerans* in improving plant spread. By combining *B. macerans* or neem cake with *P. chlamydosporia* also there was no added advantage. The effect of neem cake was on par with *P. chlamydosporia* and significantly superior to untreated (36.33 cm) giving mean plant spread of 55.67 and 61.00 cm respectively.

During the fifth month after application of treatments in main field, the effect of *P. lilacinus* + neem cake (85.00 cm) was statistically on par with *P. lilacinus* + *B. macerans* (84.67 cm), carbosulfan (83.00 cm) and *P. lilacinus* + *P. chlamydosporia* (81.67 cm). Here *P. lilacinus* in combination with bioagents (*B. macerans* and *P. chlamydosporia*) and organic amendment (neem cake) proved to be as equally effective as the chemical carbosulfan in improving plant spread.

The same trend was observed at four MAT also and the mean plant spread ranged from 72.00 to 75.00 cm. The effect of treatments, *B. macerans* + neem cake, *P. lilacinus*, *B. macerans* (at the time of planting) and *B. macerans* (one MAP) was statistically on par and inferior to the chemical, carbosulfan with mean plant spread ranging from 77.00 to 79.33 cm at four and five MAT. The combination of *P. chlamydosporia* with *B. macerans* (65.67) or neem cake (65.33) was also on par with the above treatments at four MAT. *P. chlamydosporia* and neem cake application significantly improved the plant spread at four and five MAT compared to the untreated. These two treatments showed significant variation at five MAT with mean plant spread of 64.00 and 58.67 cm, while showed statistically similar effects at four MAT giving mean plant spread of 60.67 and 60.00 cm respectively. *P. chlamydosporia* singly and in combination with neem cake exhibited significant superiority over the untreated but was inferior to the above treatments including the chemical carbosulfan at five MAT (Table 21).

Leaf Area Index

All the treatments except *P. chlamydosporia* and neem cake alone and in combination significantly improved the leaf area in *S. rotundifolius* compared to untreated at two MAT. Treatment combinations of *P. lilacinus* + neem cake (4.63) and *P. lilacinus* + *B. macerans* (4.20) showed significant superiority over all other treatments including chemical carbosulfan (3.82). Effect of main field treatments with *P. lilacinus* + *P. chlamydosporia* and

Table 22. Effect of different treatments in the main field on the leaf area index of *S. rotundifolius* at different intervals (mean of three replications)

Treatments	Leaf area index			
	2 MAT	3 MAT	4 MAT	5 MAT
P.l. (30 g m^{-2})	3.54	3.98	2.70	1.86
B.m. (30 g m^{-2})	3.54	3.87	2.52	1.83
B.m. (30 g m^{-2}) (1MAP)	3.50	3.85	2.44	1.76
P.chl. (30 g m^{-2})	3.23	3.43	2.38	1.61
NC (100 g m^{-2})	3.17	3.40	2.32	1.35
P.l. (15 g m^{-2}) + B.m. (15 g m^{-2})	4.20	5.08	3.28	2.10
P.l. (15 g m^{-2}) + P.chl. (15 g m^{-2})	3.68	4.23	2.74	1.90
P.chl. (15 g m^{-2}) + B.m. (15 g m^{-2})	3.35	3.63	2.44	1.75
P.l. (15 g m^{-2}) + NC (100 g m^{-2})	4.63	5.34	3.48	2.17
B.m. (15 g m^{-2}) + NC (100 g m^{-2})	3.64	3.99	2.71	1.88
P.chl. (15 g m^{-2}) + NC (100 g m^{-2})	3.26	3.48	2.35	1.72
Carb. (1.5 kg ai ha^{-1})	3.82	4.28	2.88	1.93
Untreated	3.16	3.30	2.24	1.29
CD (0.05)	0.23	0.33	0.26	0.19

P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans*, P.chl – *Pochonia chlamydosporia*, NC – Neem cake, Carb – Carbosulfan
MAT – Months after treatment

B. macerans + neem cake was found as effective as carbosulfan giving leaf area index of 3.68 and 3.64 respectively. All other treatments were inferior to the chemical in improving leaf area and the treatments in the order of effectiveness were *P. lilacinus*, *B. macerans* (at planting), *B. macerans* (one MAP) and *P. chlamydosporia* + *B. macerans*, the values being 3.54, 3.54, 3.50 and 3.35 respectively. The effect of these treatments was on par revealing that combining *P. chlamydosporia* with *B. macerans* and varying the time of application of *B. macerans* proved to have no significant impact on leaf area improvement.

The leaf area index of plants under various treatments exhibited statistically significant variation both at three and four MAT. All the treatments except *P. chlamydosporia* (3.43) and neem cake alone (3.40) and *P. chlamydosporia* in combination with *B. macerans* (3.63) or neem cake (3.48) showed significant superiority over the untreated (3.30) in improving the leaf area at three MAT while the above treatments also showed significant superiority over the untreated (2.24) at four MAT. The main field treatment with *P. lilacinus* + neem cake and *P. lilacinus* + *B. macerans* recorded significantly higher leaf area index at three and four MAT with values ranging from 3.28 to 5.34. These two treatments showed significant superiority over the chemical, carbosulfan in improving the leaf area index. The treatments, *P. lilacinus* + *P. chlamydosporia*, *B. macerans* + neem cake and *P. lilacinus* alone were as effective as carbosulfan in increasing the leaf area both at three and four MAT with mean leaf area index ranging from 2.70 to 3.98. There was no added advantage of combining *P. chlamydosporia* with *P. lilacinus* since *P. lilacinus* alone proved as effective as the chemical and combination of *P. chlamydosporia* + *P. lilacinus*. The effect of *B. macerans* at the time of planting was on par with *B. macerans* (one MAP) revealing that the time of application had no significant impact on the variation of leaf area both at three and four MAT. The mean leaf area index in these treatments ranged from 2.44 to 3.87.

Analysis of the data on leaf area index at the time of harvest (five MAT) revealed that there was statistically significant variation between different treatments in the main field except neem cake (1.35) compared to the untreated (1.29). The plants treated with *P. lilacinus* + neem cake recorded mean leaf area index of 2.17 followed by *P. lilacinus* + *B. macerans* (2.10) treatment. The effect of these two were statistically on par and significantly superior to the chemical, carbosulfan (1.93). The treatments, *P. lilacinus* + *P. chlamydosporia*, *B. macerans* + neem cake, *P. lilacinus* and *B. macerans* alone at planting, *B. macerans* (one MAP) and *P. chlamydosporia* + *B. macerans* were as good as the chemical, carbosulfan with mean leaf area index ranging from 1.75 to 1.90. Thus there was no added advantage in combining *P. lilacinus*, *P. chlamydosporia*, *B. macerans* and neem cake treatments. The time of application of *B. macerans* also had no significant impact in improving the leaf area. *P. chlamydosporia* alone and in combination with neem cake were inferior to the above treatments giving mean leaf area index of 1.61 and 1.72 respectively (Table 22).

4.4.2.2 Yield

The results on yield in terms of yield attributing characters are presented in Table 23. There was statistically significant variation between different main field treatments in increasing the total number of tubers per plant compared to the untreated (62.33). The effect of treatment combination *P. lilacinus* + neem cake was statistically on par with *P. lilacinus* + *B. macerans* (97.33), carbosulfan (97.00), *P. lilacinus* + *P. chlamydosporia* (95.33), *B. macerans* + neem cake (93.67) and *P. lilacinus* alone (89.33). *B. macerans* at the time of planting was statistically on par with *B. macerans* (one MAP), *P. chlamydosporia* + *B. macerans* and *P. chlamydosporia* + neem cake in increasing the number of tubers but was inferior to the chemical, carbosulfan with values ranging from 86.00 to 89.33. *P. chlamydosporia* (75.33) and neem cake (75.00)

Table 23. Effect of different treatments in main field on the yield and yield attributing characters of *S. rotundifolius* at different intervals (mean of three replications)

Treatments	Yield parameters observed at harvest								
	Total number of tubers per plant	Total number of marketable tubers per plant	Number of tubers per kg	Size of tubers (cm)	Weight of total tubers per plant (g)	Weight of total marketable tubers per plant (g)	Weight of edible portion of tubers per plant (g)	Yield per plot (kg)	Yield (t ha^{-1})
P.l. (30 g m^{-2})	89.33	43.67	131.67	14.67	426.67	350.00	290.00	7.83	19.58
B.m. (30 g m^{-2})	86.00	42.00	132.33	14.17	420.00	333.33	273.33	6.58	16.45
B.m. (30 g m^{-2}) (1MAP)	85.67	41.67	141.00	14.08	386.67	323.33	223.33	6.73	16.83
P.chl. (30 g m^{-2})	75.33	36.33	146.33	13.17	310.00	300.00	210.00	5.48	13.70
NC (100 g m^{-2})	75.00	35.33	149.67	12.83	308.33	290.00	203.33	5.47	13.68
P.l. (15 g m^{-2}) + B.m. (15 g m^{-2})	97.33	60.67	99.00	16.83	523.33	471.67	366.67	9.57	23.93
P.l. (15 g m^{-2}) + P.chl. (15 g m^{-2})	95.33	51.67	115.67	16.50	490.00	446.67	333.33	8.80	22.00
P.chl. (15 g m^{-2}) + B.m. (15 g m^{-2})	85.33	40.00	142.00	13.83	383.33	315.00	216.67	5.90	14.95
P.l. (15 g m^{-2}) + NC (100 g m^{-2})	98.33	62.00	81.67	17.50	553.33	485.00	396.67	10.16	25.40
B.m. (15 g m^{-2}) + NC (100 g m^{-2})	93.67	46.67	123.33	15.00	483.33	440.00	326.67	8.58	21.45
P.chl. (15 g m^{-2}) + NC (100 g m^{-2})	76.67	36.67	145.67	13.33	331.67	310.00	213.33	5.71	14.28
Carb. (1.5 kg ai ha^{-1})	97.00	52.00	102.67	16.83	508.33	456.67	353.33	9.10	22.75
Untreated	62.33	32.00	155.33	12.83	305.00	276.67	200.00	5.23	13.08
CD (0.05)	9.80	4.28	12.13	1.65	23.52	25.12	28.24	0.40	-

P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans*, P.chl – *Pochonia chlamydosporia*, NC – Neem cake, Carb – Carbosulfan

also showed significant superiority over the untreated in increasing the total number of tubers per plant.

All the treatments showed statistically significant superiority over the untreated (32.00) in improving the number of marketable tubers per plant. Significantly higher mean marketable number of tubers was obtained by the plants treated with *P. lilacinus* + neem cake followed by *P. lilacinus* + *B. macerans* giving mean number of 62.00 and 60.67 respectively and these two treatments showed significant superiority over the chemical (52.00). The main field treatment with *P. lilacinus* + *P. chlamydosporia* (51.67) was as effective as carbosulfan (52.00). *B. macerans* + neem cake and *P. lilacinus* alone treatments were on par and were inferior to the above treatments with 46.67 and 43.67 marketable tubers respectively. The effect of *B. macerans* at the time of planting (42.00) was inferior to the above treatments but was on par with *B. macerans* (one MAP) (41.67) and *P. chlamydosporia* + *B. macerans* (40.00) revealing that the application time and combining *P. chlamydosporia* with *B. macerans* did not significantly improve the marketable number of tubers. The application of *P. chlamydosporia* (36.33) and neem cake alone (35.33) found to be as equally effective as the combination of *P. chlamydosporia* and neem cake (36.67) revealing significant inferiority compared to the chemical. There was also no added advantage in combining *P. chlamydosporia* and neem cake.

All the treatments except *P. chlamydosporia* (310.00 g per plant) and neem cake (308.33 g) were significantly superior to the untreated (305.00 g) in improving the yield of tubers. The highest tuber yield was recorded by the *P. lilacinus* + neem cake treated plants (553.33 g) which was significantly superior to all the other treatments including the chemical, carbosulfan. The main field treatment, *P. lilacinus* + *B. macerans* (523.33 g) was as effective as chemical, carbosulfan (508.33 g) showing significant superiority over the rest of the treatments in improving the

weight of tubers per plant. The effect of treatment *P. lilacinus* + *P. chlamydosporia* was statistically on par with *B. macerans* + neem cake and inferior to the chemical showing 490.00 and 483.33 g tuber weight respectively. The effect of *P. lilacinus* and *B. macerans* at the time of planting was statistically on par with tuber weights of 426.67 and 420.00 g respectively. *B. macerans* (one MAP) (386.67 g) and *P. chlamydosporia* + *B. macerans* (383.33 g) treatments were statistically on par and inferior to the above treatments, but showed significant superiority over the treatment combination, *P. chlamydosporia* + neem cake (331.67 g).

Analysis of the data on marketable weight of tubers per plant revealed that there was statistically significant variation between the treatments in the main field and untreated (276.67 g) except *P. chlamydosporia* (300.00 g) and neem cake (290.00 g). Significantly higher marketable tuber weight per plant was recorded in *P. lilacinus* + neem cake treatment (485.00 g) closely followed by *P. lilacinus* + *B. macerans* (471.67 g) and the effect of these two was statistically on par. These two treatments showed significant superiority over the chemical carbosulfan (456.67 g) in improving the marketable tuber weight. *P. lilacinus* + *P. chlamydosporia* and *B. macerans* + neem cake treatments were as effective as the chemical carbosulfan giving mean marketable weight of tubers of 446.67 and 440.00 g respectively. Main field application of *P. lilacinus* alone (350.00 g) was as equally effective as that of *B. macerans* at the time of planting (333.33 g) while *B. macerans* (one MAP) (323.33 g) was on par with *P. chlamydosporia* + *B. macerans* (315.00 g) and *P. chlamydosporia* + neem cake (310.00 g).

Main field treatments with *P. lilacinus* + neem cake (17.50 cm), *P. lilacinus* + *B. macerans* (16.83 cm) and *P. lilacinus* + *P. chlamydosporia* (16.50 cm) were found as effective as carbosulfan (16.83 cm) in improving the size (diameter) of tubers. The effect of *B. macerans* + neem cake (15.00 cm) was on par with *P. lilacinus* alone (14.67 cm) and

was inferior to the chemical carbosulfan. These treatments in the main field showed significant superiority over the rest of treatments in which mean size of tubers ranged from 12.83 to 14.17 cm.

All the treatments except *P. chlamydosporia* + neem cake (145.67), *P. chlamydosporia* (146.33) and neem cake (149.69) alone showed significant variation in number of tubers per kg compared to the untreated (155.33). Maximum number of tubers per kg was recorded by plants treated with *P. lilacinus* + neem cake (81.67) which was significantly superior to all the other treatments including the chemical, carbosulfan. The main field treatment with *P. lilacinus* + *B. macerans* and carbosulfan were equally effective in improving the number of tubers with mean number of tubers of 99.00 and 102.67 per kg. The other treatments in the order of effectiveness were as follows. *P. lilacinus* + *P. chlamydosporia* (115.67) and *B. macerans* + neem cake (123.33) were statistically on par and were inferior to the chemical, carbosulfan. Main field treatment with *P. lilacinus, B. macerans* (at the time of planting), *B. macerans* (one MAP) and *P. chlamydosporia* + *B. macerans* were statistically on par and was inferior to the above treatments including chemical with mean tuber number of more than 142.00 per kg.

In the case of E.P. (edible portion) weight of tubers, main field treatment with *P. lilacinus* + neem cake recorded the highest tuber weight (396.67 g per plant) and it was significantly different from *P. lilacinus* + *B. macerans* (366.67 g). Both these treatments exhibited significant superiority over all other treatments including carbosulfan application (353.33 g). The treatments, *P. lilacinus* + *P. chlamydosporia* (333.33 g) and *B. macerans* + neem cake (326.67 g) were as equally effective as the chemical in increasing the E.P. weight of tubers. This was followed by *P. lilacinus* (290.00 g) and *B. macerans* (at the time of planting) (273.33 g) and these two were statistically on par and superior to the rest of treatments.

The tuber yield computed in per plot basis ranged from 5.47 to 10.16 kg in different treatments as against the mean tuber weight of 5.23 kg in untreated. Significantly higher yield was obtained in *P. lilacinus* + neem cake (10.16 kg) and *P. lilacinus* + *B. macerans* (9.57 kg) treatments which were independent of each other and showed significant superiority over all other treatments including the chemical, carbosulfan (9.10 kg). Statistically similar effect was observed in carbosulfan (9.10 kg) and *P. lilacinus* + *P. chlamydosporia* (8.80 kg) treatments. *B. macerans* + neem cake (8.58 kg) and *P. lilacinus* alone (7.83 kg) showed significant superiority over the rest of treatments in improving the tuber yield per plot. Among the rest of treatments *B. macerans* (one MAP) resulted in statistically similar effect as that of *B. macerans* at the time of planting while *P. chlamydosporia* + *B. macerans* was on par with *P. chlamydosporia* + neem cake, the values being 6.73, 6.58, 5.90 and 5.71 respectively. The per hectare yield under various treatments ranged from 14.00 to 24.00 tonnes as against 13.08 tonnes in untreated plots.

4.4.2.3 Nematode Population Characteristics

The results relating to the effect of different treatments in the main field in reducing the population characteristics of *M. incognita* are presented in Tables 24 and 25.

Nematode population in soil

There was statistically significant variation between different treatments in reducing the nematode population in soil compared to the untreated at two, four and five MAT. Population of nematodes estimated at two MAT showed significantly lower number in *P. lilacinus* + neem cake (31.54 per 250 g soil) and *P. lilacinus* + *B. macerans* (35.25 per 250 g soil) application in the main field. Main field treatment with *P. lilacinus* + *P. chlamydosporia* was found as effective as carbosulfan with 45.49 and 50.26 larvae per 250 g soil respectively. Other treatments in the order of effectiveness were *B. macerans* + neem cake, *P. lilacinus*

Table 24. Effect of different treatments in main field on the population characteristics of *M. incognita* in *S. rotundifolius* at the time of harvest (mean of three replications)

Treatments	Population of nematodes in				
	Soil (250 g)			Root (5 g)	Tuber (10 g)
	2 MAT	4 MAT	5 MAT		
P.l. (30 g m^{-2})	70.50 (1.85)	77.16 (1.89)	69.21 (1.85)	14.47 (1.19)	26.50 (1.44)
B.m. (30 g m^{-2})	74.37 (1.88)	87.24 (1.95)	73.26 (1.87)	17.55 (1.27)	28.20 (1.47)
B.m. (30 g m^{-2}) (1MAP)	84.39 (1.93)	99.53 (2.00)	76.83 (1.89)	22.32 (1.37)	34.92 (1.56)
P.chl. (30 g m^{-2})	108.97 (2.04)	112.01 (2.05)	97.00 (1.99)	40.60 (1.62)	47.63 (1.69)
NC (100 g m^{-2})	119.73 (2.08)	145.20 (2.17)	102.10 (2.01)	42.85 (1.64)	49.98 (1.71)
P.l. (15 g m^{-2}) + B.m. (15 g m^{-2})	35.25 (1.56)	54.55 (1.75)	39.65 (1.61)	5.80 (0.83)	7.88 (0.95)
P.l. (15 g m^{-2}) + P.chl. (15 g m^{-2})	45.49 (1.67)	67.26 (1.83)	51.59 (1.72)	6.96 (0.90)	14.81 (1.20)
P.chl. (15 g m^{-2}) + B.m. (15 g m^{-2})	87.24 (1.95)	93.21 (1.97)	79.24 (1.90)	29.44 (1.48)	41.57 (1.63)
P.l. (15 g m^{-2}) + NC (100 g m^{-2})	31.54 (1.51)	46.49 (1.68)	33.70 (1.54)	0.82 (0.26)	0.82 (0.26)
B.m. (15 g m^{-2}) + NC (100 g m^{-2})	68.61 (1.84)	72.46 (1.87)	65.79 (1.83)	9.88 (1.04)	21.27 (1.35)
P.chl. (15 g m^{-2}) + NC (100 g m^{-2})	97.09 (1.99)	110.25 (2.05)	89.26 (1.96)	32.98 (1.53)	42.29 (1.64)
Carb. (1.5 kg ai ha^{-1})	50.26 (1.71)	70.61 (1.86)	56.96 (1.76)	6.56 (0.88)	14.81 (1.20)
Untreated	189.31 (2.28)	245.82 (2.39)	197.44 (2.30)	73.84 (1.84)	109.71 (2.04)
CD (0.05)	(0.08)	(0.07)	(0.08)	(0.18)	(0.15)

P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans,* P.chl – *Pochonia chlamydosporia*, NC – Neem cake, Carb – Carbosulfan

MAT – Months after treatment, Figures in parenthesis are after logarithmic transformation

and *B. macerans* alone (at the time of planting), *B. macerans* (one MAP), *P. chlamydosporia* + *B. macerans* and *P. chlamydosporia* + neem cake recording 68.61 to 97.09 nematodes per 250 g soil respectively. The effect of *P. chlamydosporia* (108.97 larvae per 250 g soil) was on par with neem cake (119.73 larvae per 250 g soil) showing significant superiority over the untreated (189.31 larvae per 250 g soil) in reducing the nematode population.

At four MAT, main field treatment with *P. lilacinus* + neem cake and *P. lilacinus* + *B. macerans* recorded significantly lower population of *M. incognita* in soil. The effect of these two treatments was better than the chemical, carbosulfan giving mean population of 46.49 and 54.55 per 250 g soil respectively. The treatments, *P. lilacinus* + *P. chlamydosporia*, *B. macerans* + neem cake and *P. lilacinus* alone were as found equally effective as chemical, carbosulfan with mean population of *M. incognita* ranging from 70.61 to 77.16 per 250 g soil. *B. macerans* at the time of planting showed statistically the same effect as that of *P. chlamydosporia* + *B. macerans* and *B. macerans* (one MAP) while *P. chlamydosporia* was on par with *P. chlamydosporia* + neem cake giving mean number of larvae ranging from 87.24 to 110.25 per 250 g soil. Neem cake application (145.20 *M. incognita* per 250 g soil) also showed significant superiority over the untreated (245.82 *M. incognita* per 250 g soil).

All the treatments were effective in reducing the nematode population compared to the untreated (197.44 larvae per 250 g soil) at five MAT. The treatment combination, *P. lilacinus* + neem cake (33.70 *M. incognita* per 250 g soil) was statistically on par with *P. lilacinus* + *B. macerans* (39.65 *M. incognita* per 250 g soil). Both these treatments were statistically superior to all other treatments including chemical in reducing the nematode population. The treatments, *P. lilacinus* + *P. chlamydosporia* and carbosulfan were equally effective with 51.59 and 56.96 larvae per 250 g soil respectively. The other treatments in the order

of effectiveness were as follows. The effect of *B. macerans* + neem cake, *P. lilacinus*, *B. macerans* (at the time of planting) and *B. macerans* (one MAP) was statistically on par with 65.79, 69.21 and 73.26 *M. incognita* per 250 g soil respectively. *P. chlamydosporia* + *B. macerans* treatment combination was statistically on par with *P. chlamydosporia* + neem cake whereas *P. chlamydosporia* + neem cake was statistically on par with *P. chlamydosporia* and neem cake alone treatments in reducing the population of *M. incognita* in soil, the values being 79.24, 89.26, 97.00 and 102.10 respectively. However all the above treatments were inferior to the chemical carbosulfan in reducing the nematode population (Table 24).

Nematode Population in Root

Analysis of the data on the number of larvae in root sample revealed that there was statistically significant variation between different treatments in the main field and the untreated (73.84 larvae per five g root). Highest reduction in population was recorded in *P. lilacinus* + neem cake treatment (0.82 larvae per five g root) and it was significantly superior to all other treatments including the chemical, carbosulfan (6.56 larvae per five g root). The treatments *P. lilacinus* + *B. macerans* and *P. lilacinus* + *P. chlamydosporia* were as effective as carbosulfan the mean larval population being 5.80 and 6.96 per five g root respectively. The effect of main field application of *B. macerans* + neem cake and *P. lilacinus* was statistically on par in reducing the population of *M. incognita* with mean number of 9.88 and 14.47 per five g root respectively. Statistically similar effect was observed in plants treated with *B. macerans* at the time of planting and *B. macerans* (one MAP) with mean larval population of 17.55 and 22.32 respectively. The effects of *P. chlamydosporia* + *B. macerans*, *P. chlamydosporia* + neem cake, *P. chlamydosporia* and neem cake alone were statistically on par in reducing the nematode population in root with values ranging from 29.44 to 42.85 (Table 24).

Nematode Population in Tuber

Regarding the number of larvae per gram of tuber (10 g), maximum reduction was obtained in plants treated with *P. lilacinus* + neem cake (0.82 *M. incognita* per 10 g tuber) in the main field. It showed significant superiority over all the other treatments including carbosulfan (14.81 larvae per 10 g tuber). Main field treatment with *P. lilacinus* + *B. macerans* (7.88 larvae per 10 g tuber) was as effective as carbosulfan. *P. lilacinus* + *P. chlamydosporia* treatment gave statistically similar effect as that of *B. macerans* + neem cake which was statistically on par with *P. lilacinus* and *B. macerans* at the time of planting with mean larval population ranging from 14.81 to 28.20 per 10 g tuber. The effect of treatments, *B. macerans* (one MAP), *P. chlamydosporia* + *B. macerans*, *P. chlamydosporia* + neem cake, *P. chlamydosporia* and neem cake alone was statistically on par, the mean population of *M. incognita* ranging from 34.92 to 49.98 per 10 g tuber (Table 24).

Root-Knot Count

Regarding the root-knot count, main field treatment with *P. lilacinus* + neem cake (1.29), *P. lilacinus* + *B. macerans* (1.29) and *P. lilacinus* + *P. chlamydosporia* (1.71) were as equally effective as carbosulfan (1.47) in reducing the root-knot count. The mean root-knot index in above treatments was one. The effect of *B. macerans* + neem cake, *P. lilacinus* and *B. macerans* alone at the time of planting was statistically on par with mean root-knot count of 6.49, 10.27 and 11.63 respectively. The treatments *viz.*, *B. macerans* (one MAP), *P. chlamydosporia* + *B. macerans*, *P. chlamydosporia* + neem cake, *P. chlamydosporia* and neem cake alone treatments were statistically on par with mean root-knot count ranging from 13.80 to 27.92. The mean root-knot index in the above treatments ranged from two to five (Table 25).

Table 25. Effect of different treatments in main field on the population characteristics of *M. incognita* in *S. rotundifolius* at the time of harvest (mean of three replications)

Treatments	Root-knot count in 5 g root	Root-knot index	Number of females in 5 g root	Number of egg masses in 5 g root	Number of eggs per egg mass
P.l. (30 g m^{-2})	10.27 (1.05)	2	21.61 (1.35)	10.66 (1.07)	66.06 (1.83)
B.m. (30 g m^{-2})	11.63 (1.10)	3	22.25 (1.37)	12.18 (1.12)	78.95 (1.90)
B.m. (30 g m^{-2}) (1MAP)	13.80 (1.17)	3	24.11 (1.40)	12.51 (1.13)	89.40 (1.96)
P.chl. (30 g m^{-2})	14.94 (1.20)	4	34.92 (1.56)	22.25 (1.37)	140.91 (2.15)
NC (100 g m^{-2})	27.92 (1.46)	5	37.92 (1.59)	24.50 (1.41)	221.52 (2.35)
P.l. (15 g m^{-2}) + B.m. (15 g m^{-2})	1.29 (0.36)	1	1.29 (0.36)	0.82 (0.26)	2.42 (0.53)
P.l. (15 g m^{-2}) + P.chl. (15 g m^{-2})	1.71 (0.43)	1	4.43 (0.74)	5.34 (0.80)	45.99 (1.67)
P.chl. (15 g m^{-2}) + B.m. (15 g m^{-2})	14.58 (1.19)	3	27.96 (1.46)	14.81 (1.20)	132.77 (2.13)
P.l. (15 g m^{-2}) + NC (100 g m^{-2})	1.29 (0.36)	1	0.82 (0.26)	0.44 (0.16)	2.21 (0.51)
B.m. (15 g m^{-2}) + NC (100 g m^{-2})	6.49 (0.87)	2	16.31 (1.24)	7.41 (0.93)	61.60 (1.80)
P.chl. (15 g m^{-2}) + NC (100 g m^{-2})	14.58 (1.19)	3	29.96 (1.49)	14.07 (1.18)	130.98 (2.12)
Carb. (1.5 kg ai ha^{-1})	1.47 (0.39)	1	1.71 (0.43)	1.35 (0.37)	9.65 (1.03)
Untreated	55.64 (1.75)	5	64.25 (1.82)	12.74 (1.14)	326.26 (2.52)
CD (0.05)	(0.29)		(0.40)	(0.73)	(0.69)

P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans,* P.chl – *Pochonia chlamydosporia*, NC – Neem cake, Carb – Carbosulfan

Figures in parenthesis are after logarithmic transformation

Number of Females

There was statistically significant variation in the production of females (per five g root) in all the treatments compared to the untreated (64.25) except *P. chlamydosporia* (34.92) and neem cake (37.92) singly and in combination (29.96). *P. lilacinus* + neem cake (0.82), *P. lilacinus* + *B. macerans* (1.29) and chemical carbosulfan (1.71) treatments were statistically on par in reducing the number of females. The other treatments in the order of effectiveness were *P. lilacinus* + *P. chlamydosporia*, *B. macerans* + neem cake, *P. lilacinus* and *B. macerans* at the time of planting and *B. macerans* (one MAP) with mean number of females ranging from 4.43 to 24.11 per five g root. The effect of these treatments was statistically on par and inferior to the chemical, carbosulfan but was significantly superior to the untreated (Table 25).

Number of Egg Masses per Root

There was statistically significant variation in the number of egg masses per root between different treatments and the untreated (12.74 per five g root). The treatments, *P. lilacinus* + neem cake, *P. lilacinus* + *B. macerans*, *P. lilacinus* + *P. chlamydosporia*, *B. macerans* + neem cake and *P. lilacinus* alone were as effective as the chemical, carbosulfan in reducing the number of egg masses per root system, the mean number of egg masses ranging from 0.44 to 10.66. The other treatments in the order of effectiveness were *B. macerans* at planting, *B. macerans* at one MAP, *P. chlamydosporia* + neem cake, *P. chlamydosporia* + *B. macerans*, *P. chlamydosporia* and neem cake (from 12.18 to 24.50 egg masses per root system). These treatments showed significant superiority over the untreated but were inferior to the chemical revealing that there was no added advantage in combined application of *B. macerans* and *P. chlamydosporia*. The time of application of *B. macerans* also had no

significant effect in reducing the number of egg masses per root system (Table 25).

Number of Eggs per Egg Mass

All the treatments in the main field were significantly superior in reducing the number of eggs per egg masses compared to the untreated (326.26). Significantly lower number of eggs per egg mass was recorded in *P. lilacinus* + neem cake treatment and it was statistically on par with *P. lilacinus* + *B. macerans* showing significant superiority over the chemical, carbosulfan. The mean number of eggs per egg mass in the above 2 treatments was 2.21 and 2.42 respectively. Main field treatment with *P. lilacinus* + *P. chlamydosporia* was as effective as carbosulfan giving mean number of 9.65 and 45.99 eggs respectively. All other treatments showed significant superiority over the untreated in reducing the eggs per egg mass but were inferior to the recommended chemical, carbosulfan giving mean number of eggs per egg mass ranging from 61.60 to 221.52.

4.4.2.4 Quality Parameters

The data presented in Table 26 indicated the effect of different selected main field treatments on the quality parameters of *S. rotundifolius*.

Protein

Among the selected treatments, *P. lilacinus* + neem cake, *P. lilacinus* + *B. macerans* and untreated were statistically on par in the case of protein content of tubers, the values being 8.48, 8.46 and 8.67 g per 100 g dry weight of tuber respectively. The treatments, *P. lilacinus* + *P. chlamydosporia* and carbosulfan recorded protein content of 7.87 and 7.72 g per 100 g dry weight of tuber respectively and the effect of these two were statistically on par. In the untreated plants, due to nematode infestation the protein content increased.

Table 26. Effect of selected treatments from the main field on the quality parameters of *S. rotundifolius* tubers after harvest (mean of three replications)

Treatments	Protein (g / 100 g dry weight of tuber)	Percentage change of protein over the untreated	Starch (g / 100 g dry weight of tuber)	Percentage increase of starch over the untreated	Sugar (g / 100 g dry weight of tuber)	Percentage increase of sugar over the untreated	Crude fibre (g / 100 g dry weight of tuber)	Percentage increase of crude fibre over the untreated
P.l. (15 g m^{-2}) + B.m. (15 g m^{-2})	8.46	-0.24	17.44	18.40	3.52	31.34	1.40	50.54
P.l. (15 g m^{-2}) + P.chl. (15 g m^{-2})	7.87	-7.19	17.03	15.61	3.15	17.54	1.23	32.26
P.l. (15 g m^{-2}) + NC (100 g m^{-2})	8.67	+2.24	17.96	21.93	3.68	37.31	1.43	53.76
B.m. (15 g m^{-2}) + NC (100 g m^{-2})	6.48	-23.58	17.37	17.92	2.77	3.36	1.01	8.60
Carb. (1.5 kg ai ha^{-1})	7.72	-8.96	16.84	14.32	3.20	19.40	1.37	47.31
Untreated	8.48	-	14.73	-	2.68		0.93	-
CD (0.05)	0.68		0.49		0.50		0.37	

P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans,* P.chl – *Pochonia chlamydosporia*, NC – Neem cake, Carb – Carbosulfan

Starch

Regarding the starch content of the tubers, highest (22.00 per cent over untreated) was recorded by *P. lilacinus* + neem cake treatment and it was significantly superior to all the other treatments. The effect of *P. lilacinus* + *B. macerans*, *B. macerans* + neem cake and *P. lilacinus* + *P. chlamydosporia* was statistically on par and recorded 17.92 to 18.40 per cent increase over the untreated. The chemical treatment carbosulfan resulted an increase of 15.61 per cent over untreated.

Sugar

Significantly higher sugar content was recorded by *P. lilacinus* + neem cake treatment and it was statistically on par with *P. lilacinus* + *B. macerans* and carbosulfan. The percentage increase in the above treatments ranged from 19.00 to 37.00 per cent. The effect of treatments, *P. lilacinus* + *P. chlamydosporia* (3.15 g per 100 g dry weight of tuber), *B. macerans* + neem cake (2.77 g per 100 g dry weight of tuber) and untreated (2.68) were statistically on par revealing that there was no significant effect on sugar content by applying *P. lilacinus* + *P. chlamydosporia* and *B. macerans* + neem cake treatments.

Crude Fibre

In the case of crude fibre, the effect of *P. lilacinus* + neem cake, *P. lilacinus* + *B. macerans*, carbosulfan and *P. lilacinus* + *P. chlamydosporia* treatments was statistically on par showing 32.00 to 54.00 per cent increase over the untreated. There was no significant improvement in crude fibre content by the *B. macerans* + neem cake treatment as it was statistically on par with untreated.

4.4.2.5 Estimation of bioagents from the root and rhizosphere

Reisolation of *P. lilacinus* from the rhizosphere recorded 52 colony forming units (cfu) in Rose bengal agar and 42 cfu in potato dextrose agar at 10^{-3} dilution. In the case of *P. chlamydosporia* as main field treatment

it was 30 cfu in Rose bengal agar and 22 cfu in potato dextrose agar at 10^{-3} dilution. In the case of *B. macerans,* there were 20 colonies in 10^{-6} dilution.

4.4.3 Integrated Nematode management

The effect of bioagents, organic amendment, physical methods was evaluated singly and in combination in the nursery and main field with the recommended chemical, carbosulfan as check. The selected treatments in the nursery as well as main field were evaluated in an integrated manner using selected variety Sree Dhara. The effect of the above treatments were assessed in terms of improvement in biometric characters, yield and reduction in population of nematodes at different intervals and quality parameters of the tubers at the time of harvest. The results on the above are presented in Tables 27 to 33.

4.4.3.1 Biometric Characters

The results relating to the effect of integration of selected treatments from nursery and main field in improving the height, number of leaves, number of branches, plant spread and leaf area index of *S. rotundifolius* plants are presented in Tables 27 to 29.

Plant Height

Regarding the plant height, all the treatments except nursery treatment (N) of carbosulfan and main field treatment (M) of *P. lilacinus* + neem cake were significantly higher than the untreated at one and two months after treatment (MAT). Among the effective treatments, the effect of solarization (N) + (*P. lilacinus* + neem cake) (M) was statistically on par with *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M), solarization (N) + (*P. lilacinus* + *B. macerans*) (M), *B. macerans* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M), carbosulfan (N) + carbosulfan (M), solarization (N) + carbosulfan (M), *P. lilacinus* (N) + (*P. lilacinus* +*B. macerans*) (M) and *P. lilacinus* (N) +

Table 27. Effect of integrated application of selected treatment s from nursery and main field on the biometric characters of *S. rotundifolius* at different intervals (mean of three replications)

Treatments	Biometric characters observed at monthly intervals									
	Height of plant (cm)					Number of leaves				
	1 MAT	2 MAT	3 MAT	4 MAT	5 MAT	1 MAT	2 MAT	3 MAT	4 MAT	5 MAT
S (N) + (P.l. + NC) (M)	25.67	33.00	45.67	61.33	64.33	422.67	743.33	954.00	875.00	593.33
S (N) + (P.l. + B.m.) (M)	25.33	30.00	44.00	61.33	60.33	404.33	726.67	926.67	853.33	583.33
S (N) + (C) (M)	23.00	25.33	41.00	53.33	52.67	241.33	620.00	843.33	773.33	450.00
P.l. (N) + (P.l. + NC) (M)	25.67	29.33	44.33	59.67	59.00	403.33	720.00	903.33	833.33	583.33
P.l. (N) + (P.l. + B.m.) (M)	23.00	27.33	41.00	55.00	55.33	316.67	633.33	866.67	780.00	493.33
P.l. (N) + (C) (M)	22.67	24.00	40.67	52.33	52.33	241.00	606.67	833.33	753.33	416.67
B.m (N) + (P.l. + NC) (M)	25.33	29.00	44.33	57.67	58.33	340.00	706.67	903.33	831.67	553.33
B.m (N) + (P.l. + B.m.) (M)	24.00	28.67	44.00	56.00	56.33	338.67	666.67	890.00	830.00	553.33
B.m (N) + (C) (M)	20.67	26.67	39.67	54.00	53.67	250.67	630.00	858.33	766.67	376.67
C (N) + (P.l. + NC) (M)	19.67	21.67	38.33	50.33	52.33	224.33	603.33	833.33	746.67	450.00
C (N) + (P.l. + B.m.) (M)	21.00	22.00	38.00	47.67	52.00	221.67	593.33	803.33	706.67	376.67
C (N) + (C) (M)	23.33	28.33	41.67	55.00	55.67	329.67	636.67	873.33	806.67	550.00
Untreated	16.33	19.00	29.33	38.00	40.00	218.00	446.67	626.67	626.67	310.00
CD (0.05)	3.44	2.87	3.57	5.34	8.10	21.94	34.40	29.82	35.50	47.36

S – Solarization, N – Nursery treatment, P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans*, NC – Neem cake, Carb – Carbosulfan
MAT – Months after treatment

carbosulfan (M) with mean plant heights ranging from 22.67 to 25.67 cm at one MAT. These treatments were as equally effective as the chemical treatment, carbosulfan both in the nursery and main field. When the plant height was recorded at two MAT, maximum was recorded by solarization (N) + (*P. lilacinus* + neem cake) (M) with mean plant height of 33.00 cm and was significantly superior to all other treatments including carbosulfan application in nursery and main field. Solarization (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M), carbosulfan (N) + carbosulfan (M) and *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) treatments were statistically on par with mean plant height ranging from 27.33 to 30.00 cm. The effect of *B. macerans* (N) + carbosulfan (M), solarization (N) + carbosulfan (M) and *P. lilacinus* (N) + carbosulfan (M) treatments was statistically on par showing mean plant height of 26.67. 25.33 and 24.00 cm respectively. Carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) (22.00 cm) showed statistically the same effect as that of carbosulfan (N) + (*P. lilacinus* + neem cake) (M) (21.67 cm) but was significantly superior to untreated (19.00 cm).

The effect of different treatment combinations on plant height expressed during the third month revealed that in solarization (N) + (*P. lilacinus* + neem cake) (M), *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) + (*P. lilacinus* + neem cake) (M), solarization (N) + (*P. lilacinus* + *B. macerans*) (M) and *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) was statistically on par with mean plant height ranging from 44.00 to 45.67 cm. A similar trend was observed at four and five MAT with mean plant height ranging from 56.00 to 61.33 cm and 56.33 to 64.33 cm respectively. The effect of the above treatment combinations were better than the chemical, carbosulfan application in nursery and main field at three, four and five MAT. The treatments carbosulfan (N) + carbosulfan (M), *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M),

solarization (N) + carbosulfan (M), *P. lilacinus* (N) + carbosulfan (M), *B. macerans* (N) + carbosulfan (M) and carbosulfan (N) + (*P. lilacinus* + neem cake) (M) were statistically on par with height of plants ranging from 38.33 to 41.67 cm and 50.33 to 55.00 cm at three and four MAT respectively. The effect of carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) was also found to be statistically on par with the above treatment combinations in improving the plant height at five MAT and the values ranged from 52.00 to 55.67 cm. (Table 27).

Number of Leaves

There was statistically significant variation between different treatment compared to untreated in improving the number of leaves. The effect of solarization (N) + (*P. lilacinus* + neem cake) (M) was statistically on par with solarization (N) + (*P. lilacinus* + *B. macerans*) (M) and *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) at one and two MAT. These treatments were significantly superior to the chemical treatment in nursery and main field with mean number of leaves ranging from 403.33 to 422.67 and 720.00 to 743.33 at one and two MAT respectively. *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) (340.00) was statistically on par with *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) (338.67) and carbosulfan (N) + carbosulfan (M) (329.67) at one MAT while *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) (706.67) showed significant superiority over these two treatments at two MAT. The treatment combinations *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M), *B. macerans* (N) + carbosulfan (M), solarization (N) + carbosulfan (M) and *P. lilacinus* (N) + carbosulfan (M) were statistically on par with mean number of leaves ranging from 241.00 to 316.67 at one MAT. While at two MAT, the effect of treatment combination carbosulfan (N) + (*P. lilacinus* + neem cake) (M) also was statistically on par with the above treatment combinations with 603.33 to 633.33 leaves. There was no statistically significant difference between carbosulfan (N) + (*P. lilacinus*

+ neem cake) (M) (224.33) carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) (221.67) treatments compared to the untreated (218.00) at one MAT, but treatment combinations, carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) (593.33) showed significant superiority over the untreated (446.67) at two MAT.

The effect of solarization (N) + (*P. lilacinus* + neem cake) (M) was statistically on par with solarization (N) + (*P. lilacinus* + *B. macerans*) (M) at three and four MAT, the values ranged from to 926.67 to 954.00 and 853.33 to 875.00 respectively. The treatment combinations, *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) (903.33) and *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) (903.33) were as equally effective as solarization (N) + (*P. lilacinus* + *B. macerans*) (M) (926.67) at three MAT while solarization (N) + (*P. lilacinus* + *B. macerans*) (M) (853.33) showed significant superiority over these two treatments at four MAT with 831.67 and 833.33 leaves respectively. Nursery treatment with *P. lilacinus* or *B. macerans* in combination with (*P. lilacinus* + *B. macerans*) (M) was as equally effective as chemical, carbosulfan treatment in nursery and main field at three MAT with mean leaf number ranging from 866.67 to 890.00. The effect of *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) (833.33) was as good as the chemical treatment, carbosulfan (873.33) in nursery and main field at four MAT. The effect of *B. macerans* (N) + carbosulfan (M), solarization (N) + carbosulfan (M) + *P. lilacinus* (N) + carbosulfan (M) and carbosulfan (N) + (*P. lilacinus* + neem cake) (M) treatments were statistically on par producing 858.33, 843.33, 833.33 and 833.33 leaves at three MAT respectively. A similar trend was observed during the fourth month also but the effect of *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) was found to be on par with above treatments with mean number of leaves ranging from 746.67 to 780.00. The treatment combination carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) showed significant superiority over the untreated with mean number of leaves of 803.33 and 706.67 at three and four MAT respectively. Significantly higher number of

leaves was observed in solarization (N) + (*P. lilacinus* + neem cake) (M), solarization (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) +(*P. lilacinus* + neem cake) (M), *B. macerans* (N) +(*P. lilacinus* + *B. macerans*) (M), and carbosulfan (N) + carbosulfan (M) treatment combinations at five MAT, the values being 593.33, 583.33, 583.33, 553.33, 553.33 and 550.00 respectively. The effect of these six treatments were statistically on par and as equally effective as the chemical showing significant superiority over the rest of treatments. Among the rest of treatments, the effect of *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) was statistically on par with carbosulfan (N) + (*P. lilacinus* + neem cake) (M) and solarization (N) + carbosulfan (M) while *P. lilacinus* (N) + carbosulfan (M) was on par with *B. macerans* (N) + carbosulfan (M) and carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M). The mean number of leaves in the above treatments ranged from 376.67 to 493.33 (Table 27).

Number of Branches

Analysis of the data on the number of branches showed statistically significant variation among treatments compared to the untreated at two and five MAT (Table 28). Solarization (N) + (*P. lilacinus* + neem cake) (M), solarization (N) + (*P. lilacinus* + *B. macerans*) (M) and *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) treatment combinations were statistically on par giving mean number of branches ranging from 28.67 to 30.67 at one MAT. A similar trend was observed at three MAT also with 66.67 to 70.00 branches. *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) (26.33) and *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) (24.33) treatments were found to be as equally effective as the chemical application (24.00) in nursery and main field at one MAT. However the chemical treatment (58.33) was inferior to the above treatments at three MAT with mean number of leaves of 64.67 and 64.33 respectively. The effect of *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) was

Table 28. Effect of integrated application of selected treatments from nursery and main field on the biometric characters of *S. rotundifolius* at different intervals (mean of three replications)

Treatments	Biometric characters observed at monthly intervals									
	Number of branches					Plant spread (cm)				
	1 MAT	2 MAT	3 MAT	4 MAT	5 MAT	1 MAT	2 MAT	3 MAT	4 MAT	5 MAT
S (N) + (P.l. + NC) (M)	30.67	47.67	70.00	68.00	87.00	54.00	61.67	72.33	79.00	91.67
S (N) + (P.l. + B.m.) (M)	29.33	46.33	68.33	64.67	84.67	51.67	59.00	70.67	76.00	90.00
S (N) + (C) (M)	20.00	35.00	44.67	55.67	72.33	35.33	50.67	61.67	64.33	72.33
P.l. (N) + (P.l. + NC) (M)	28.67	42.33	66.67	63.33	80.00	47.33	55.33	70.33	75.00	87.00
P.l. (N) + (P.l. + B.m.) (M)	23.00	38.00	46.67	58.00	75.00	41.00	51.33	65.00	65.33	74.00
P.l. (N) + (C) (M)	19.67	32.67	41.33	51.33	70.33	35.00	50.33	59.33	64.00	71.00
B.m (N) + (P.l. + NC) (M)	26.33	41.67	64.33	63.33	78.67	45.33	53.67	70.33	71.67	83.67
B.m (N) + (P.l. + B.m.) (M)	24.33	41.00	64.67	62.33	78.67	43.00	52.33	67.67	71.67	81.00
B.m (N) + (C) (M)	22.33	35.33	46.67	58.00	72.67	40.00	51.33	62.33	64.33	72.33
C (N) + (P.l. + NC) (M)	18.00	31.00	37.33	51.00	65.67	34.33	47.33	58.33	61.67	65.33
C (N) + (P.l. + B.m.) (M)	17.00	30.00	37.00	51.00	49.33	33.00	41.00	55.00	58.33	65.00
C (N) + (C) (M)	24.00	40.00	58.33	61.67	76.33	41.67	52.33	65.00	65.67	75.33
Untreated	16.33	27.00	36.33	38.00	48.00	30.00	35.67	42.33	45.00	55.33
CD (0.05)	2.97	4.21	5.24	4.20	5.66	4.33	3.88	4.73	5.54	4.70

S – Solarization, N – Nursery treatment, M – Main field treatment, P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans*, NC – Neem cake, Carb – Carbosulfan, MAT – Months after treatment

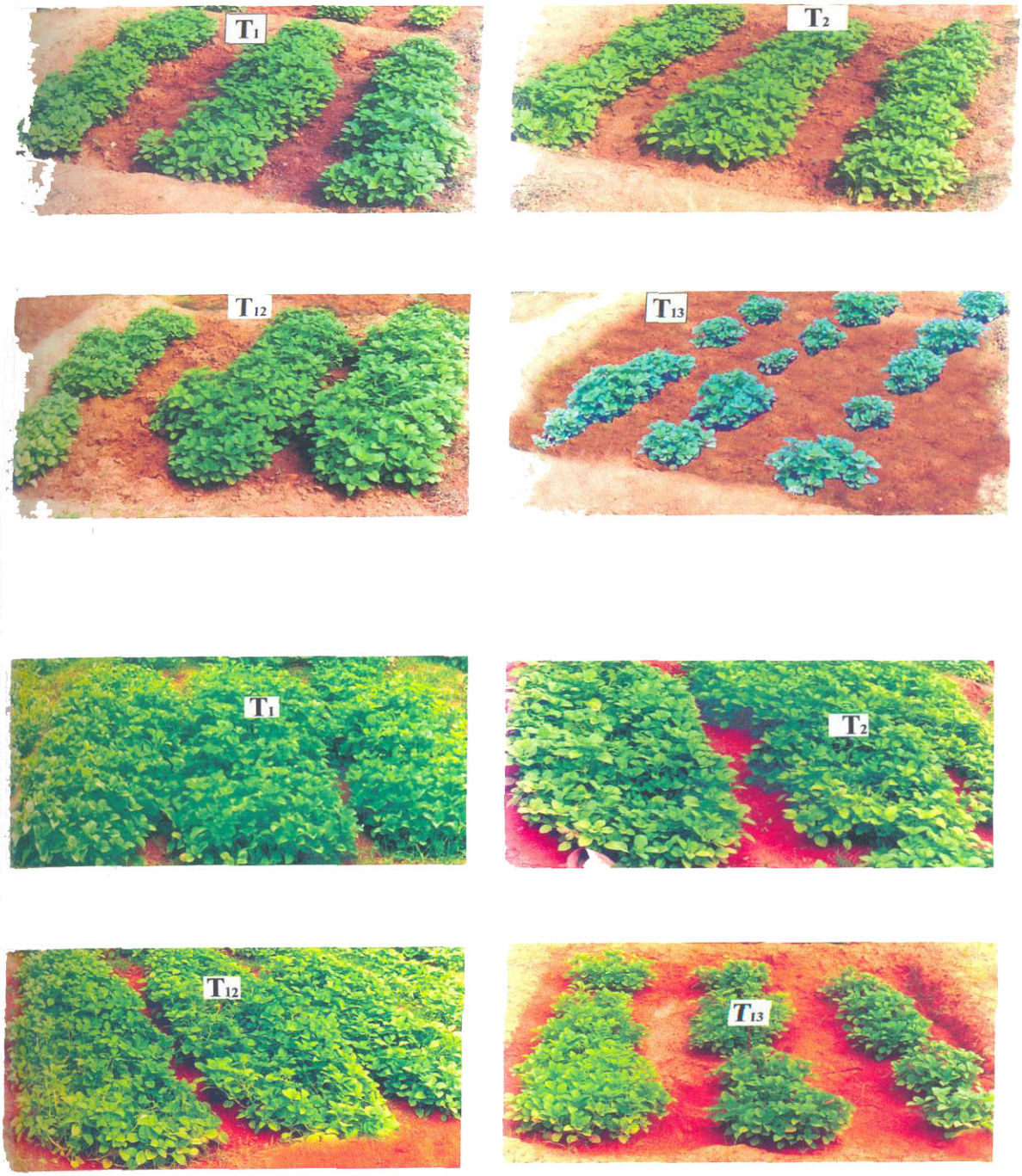
statistically on par with *B. macerans* (N) + carbosulfan (M) with mean number of branches of 23.00 and 22.33 respectively at one MAT, while at three MAT solarization (N) + carbosulfan (M) was also found to be statistically on par with the above treatments with mean number of branches ranging from 44.67 to 46.67. Solarization (N) + carbosulfan (M), *P. lilacinus* (N) + carbosulfan (M) and carbosulfan (N) + (*P. lilacinus* + neem cake) (M) treatment combinations were statistically on par with mean number of branches, 20.00, 19.67 and 18.00 respectively showing significant superiority over carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) (17.00) at one MAT. There was however no significant variation between *P. lilacinus* (N) + carbosulfan (M) (41.33), carbosulfan (N) + (*P. lilacinus* + neem cake) (M) (37.33), carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) (37.00) and untreated (36.33) at three MAT.

The effect of solarization (N) + (*P. lilacinus* + neem cake) (M) was on par with solarization (N) + (*P. lilacinus* + *B. macerans*) (M) at two, four and five MAT. The above treatment combinations showed significant superiority over the chemical, carbosulfan application both in nursery and main field with values of 47.67 and 46.33; 68.00 and 64.67; 87.00 and 84.67 at two, four and five MAT respectively. The effect of treatment combinations, *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) and *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) was statistically on par with the chemical, carbosulfan both in nursery and main field with values ranging from 40.00 to 42.33 and 61.67 to 63.33 respectively at two and four MAT. The *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) also found as equally effective as the above treatments at five MAT with mean number of branches ranging from 75.00 to 80.00. Treatment combination *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) was statistically on par with *B. macerans* (N) + carbosulfan (M) and solarization (N) + carbosulfan (M), while *P. lilacinus* (N) + carbosulfan (M) was on par with carbosulfan (N) + (*P. lilacinus* + neem cake) (M) and carbosulfan (N) +

(*P. lilacinus* + *B. macerans*) (M) with mean number of branches ranging from 30.00 to 38.00 at two MAT. A similar trend was observed at four MAT also with values of 58.00, 58.00, 55.67, 51.33, 51.00 and 51.00 respectively. The effect of *B. macerans* (N) + carbosulfan (M) (72.67) was on par with solarization (N) + carbosulfan (M) (72.33), while solarization (N) + carbosulfan (M) (72.33) showed statistically similar effect as that of *P. lilacinus* (N) + carbosulfan (M) (70.33) and carbosulfan (N) + (*P. lilacinus* + neem cake) (M) (65.67) at five MAT. These four treatment combinations showed significant superiority over carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) with mean number of branches of 49.33 (Table 28).

Plant Spread

The plant spread of *S. rotundifolius* plants recorded at different intervals showed significant variation compared to the untreated (Table 28). The treatment combinations, solarization (N) + (*P. lilacinus* + neem cake) (M) and solarization (N) + (*P. lilacinus* + *B. macerans*) (M) at one MAT were statistically on par. The effect of *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) and *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) was statistically on par at one MAT. These five treatments exhibited significant superiority over carbosulfan (41.67 cm) with mean plant spread ranging from 43.00 to 54.00 cm at one MAT. At two MAT, carbosulfan (N) + carbosulfan (M) also was statistically on par with the above showing mean plant spread ranging from 52.33 to 61.67 cm. Treatment combinations of *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M), *B. macerans* (N) + carbosulfan (M), solarization (N) + carbosulfan (M), *P. lilacinus* (N) + carbosulfan (M), carbosulfan (N) + (*P. lilacinus* + neem cake) (M) and carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) were as equally effective as carbosulfan application both in nursery as well as main field and improved the plant spread to the tune of 33.00 to 41.67 cm at one MAT. However at



T_1 - Solarization (Nursery) + (*P. lilacinus* + neem cake) (main field)
T_2 - Solarization (Nursery) + (*P. lilacinus* + *B. macerans*) (main field)
T_{12} - Carbosulfan (Nursery) + (Carbosulfan) (main field)
T_{13} - Untreated

Plate 8. Effect of integration of selected treatments from nursery and main field on the growth of *S. rotundifolius* at 20 days after planting and two MAP

two MAT, the effect of the above treatments were significantly inferior to the chemical with mean plant spread ranging from 41.00 to 51.33 cm (Plate 8).

The effect of solarization in nursery and *P. lilacinus* + neem cake in main field, solarization (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) and *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) were statistically on par and significantly superior to the chemical at three MAT with mean plant spread of more than 67.67 cm. *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M), *B. macerans* (N) + carbosulfan (M) and solarization (N) + carbosulfan (M) treatment combinations were statistically on par compared to carbosulfan application both in nursery and main field and the effect of these treatment combinations was significantly superior to *P. lilacinus* (N) + carbosulfan (M), carbosulfan (N) + (*P. lilacinus* + neem cake) (M) and carbosulfan (N) + (*P. lilacinus* + *B. macerans* (M) which were at par. The mean plant spread in the above treatment combinations ranged from 55.00 to 65.00 cm.

The effect of the treatments, solarization (N) + (*P. lilacinus* + neem cake) (M) was on par with solarization (N) + (*P. lilacinus* + *B. macerans*) (M) and *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) at four and five MAT. The plant spread ranged from 75.00 to 79.00 cm and 87.00 to 91.67 cm at four and five MAT respectively. The treatments, solarization (N) + (*P. lilacinus* + *B. macerans*) (M) (76.00 cm), *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) (75.00 cm), *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) (71.67 cm), *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) (71.67 cm) were statistically on par and significantly superior to carbosulfan application in the nursery and main field (65.67 cm) at four MAT while the combination of *B. macerans* in nursery and combination of *P. lilacinus* with either neem cake (83.67 cm) or *B. macerans* (81.00 cm) as main field treatment was inferior to the above treatments and significantly superior to the chemical applications in the nursery and main field (75.33 cm) at five MAT. The treatment combinations,

carbosulfan (N) + carbosulfan (M), *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M), solarization (N) + carbosulfan (M), *B. macerans* (N) + carbosulfan (M), *P. lilacinus* (N) + carbosulfan (M) and carbosulfan (N) + (*P. lilacinus* + neem cake) (M) were statistically on par showing significant superiority over carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) at four MAT. The mean plant spread in these treatment combinations ranged from 58.33 to 65.67 cm.

Leaf Area Index

There was statistically significant variation in the leaf area index of *S. rotundifolius* plants after the application of different nursery and main field treatments in an integrated manner (Table 29). Nursery solarization plus (*P. lilacinus* + neem cake) application in main field was statistically on par with solarization (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) and *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) at two MAT. The above treatment combinations exhibited significant superiority over the application of chemical in nursery and main field with mean leaf index ranging from 3.91 to 4.23. The effect of *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M), solarization (N) + carbosulfan (M) and *P. lilacinus* (N) + carbosulfan (M) was as equally effective as carbosulfan application both in nursery and main field (3.75) showing mean leaf area index of 3.68, 3.57 and 3.47 respectively at two MAT.

At four MAT, the effect of solarization (N) + (*P. lilacinus* + neem cake) (M) (3.82) and *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) (3.69) was statistically on par and significantly superior to the rest of the treatments. The effect of *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) (3.53) was statistically on par with solarization (N) + (*P. lilacinus* + *B. macerans*) (M) (3.55) and *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) (3.50) showing significant superiority over the chemical carbosulfan as nursery and main field treatment. Statistically similar

Table 29. Effect of integrated application of selected treatments from nursery and main field on leaf area index of *S. rotundifolius* at different intervals (mean of three replications)

Treatments	Leaf area index			
	2 MAT	3 MAT	4 MAT	5 MAT
S (N) + (P.l. + NC) (M)	4.23	5.13	3.82	2.82
S (N) + (P.l. + B.m.) (M)	4.12	4.47	3.55	2.41
S (N) + (C) (M)	3.57	3.84	2.62	1.68
P.l. (N) + (P.l. + NC) (M)	3.95	4.29	3.53	2.42
P.l. (N) + (P.l. + B.m.) (M)	3.68	3.84	2.72	1.82
P.l. (N) + (C) (M)	3.47	3.74	2.62	1.62
B.m (N) + (P.l. + NC) (M)	3.92	4.27	3.69	2.21
B.m (N) + (P.l. + B.m.) (M)	3.91	4.15	3.50	1.84
B.m (N) + (C) (M)	3.32	3.37	2.60	1.59
C (N) + (P.l. + NC) (M)	3.17	3.59	2.45	1.48
C (N) + (P.l. + B.m.) (M)	3.39	3.71	2.61	1.61
C (N) + (C) (M)	3.75	4.07	2.84	1.86
Untreated	3.14	3.36	2.42	1.36
CD (0.05)	0.33	0.25	0.23	0.20

S – Solarization, N – Nursery treatment, M – Main field treatment, P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans,* NC – Neem cake, Carb – Carbosulfan, MAT – Months after treatment

effect was observed among carbosulfan (N) + carbosulfan (M), *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + carbosulfan (M) , solarization (N) + carbosulfan (M) and carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) treatments with mean leaf area index ranging from 2.61 to 2.84. Solarization (N) + (*P. lilacinus* + neem cake) (M) recorded maximum leaf area index at three and five MAT with values of 5.13 and 2.82 respectively. It showed significant superiority over all the other treatments. The treatment combinations, solarization (N) + (*P. lilacinus* + *B. macerans*) (M) (4.47) was statistically on par with *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) (4.29) and *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) (4.27) showing significant superiority over the chemical (4.07) at three MAT. *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) (4.15) found as equally effective as carbosulfan application both in the nursery and main field (4.07) in increasing the leaf area. The treatment combinations, *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M), solarization (N) + carbosulfan (M), *P. lilacinus* (N) + carbosulfan (M), carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) and carbosulfan (N) + (*P. lilacinus* + neem cake) were statistically on par and significantly inferior to the chemical with mean leaf area index ranging from 3.59 to 3.84 at three MAT. The effect of solarization (N) + (*P. lilacinus* + *B. macerans*) (M) was statistically on par with *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) and *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) at five MAT and these treatments showed significant superiority over the chemical, carbosulfan application in nursery and main field with mean leaf area index ranging from 2.21 to 2.42. The treatment combinations *viz*., carbosulfan (N) + carbosulfan (M), *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) and solarization (N) + carbosulfan (M) were statistically on par with mean leaf area index of 1.86, 1.84, 1.82 and 1.68 respectively at five MAT. These treatment combinations exhibited significant superiority over *P. lilacinus* (N) + carbosulfan (M), carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M),

B. macerans (N) + carbosulfan (M) and carbosulfan (N) + (*P. lilacinus* + neem cake) (M) showing mean leaf area index to the tune of 1.48 to 1.62.

4.4.3.2 Yield

There was statistically significant variation the treatments with regard to the yield attributing characters and the results are presented in Table 30. All the treatments except *P. lilacinus* (N) + carbosulfan (M) (77.33), carbosulfan (N) + (*P. lilacinus* + neem cake) (M) (74.00) and carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) (70.00) showed significant variation in improving the total number of tuber per plant compared to the untreated (68.33). The effect of solarization (N) + (*P. lilacinus* + neem cake) (M) was as equally effective as solarization (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) and the chemical, carbosulfan both in the nursery and main field with 90.00 and to 98.00 tubers per plant respectively. The treatment combinations of *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) (88.00), *B. macerans* (N) + carbosulfan (M) (88.00) and solarization (N) + carbosulfan (M) (81.00) were found to be equally effective and significantly superior to the above treatments.

In the case of total number of marketable tubers per plant, all the treatment combinations except carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) (38.33) showed significant superiority compared to the untreated (35.33). Significantly higher number of tubers was recorded by solarization (N) + (*P. lilacinus* + neem cake) (M) (70.00) treatment and it was statistically on par with solarization (N) + (*P. lilacinus* + *B. macerans*) (M) (68.33). *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) (63.33) was as equally effective as solarization (N) + (*P. lilacinus* + *B. macerans*) (M) but was significantly inferior to solarization (N) + (*P. lilacinus* + neem cake). These 3 treatment combinations exhibited significant superiority over the chemical treatment, carbosulfan (53.33) in the nursery and main

Table 30. Effect of integrated application of selected treatments from nursery and main field on the yield and yield attributing characters of *S. rotundifolius* (mean of three replications)

Treatments	Total number of tubers per plant	Total number of marketable tubers per plant	Number of tubers per kg	Size of tubers (cm)	Weight of total tubers per plant (g)	Weight of total marketable tubers per plant (g)	Weight of edible portion of tubers per plant (g)	Yield per plot (kg)	Yield (t ha^{-1})
S (N) + (P.l. + NC) (M)	98.00	70.00	82.33	18.83	560.00	490.00	396.67	11.50	28.75
S (N) + (P.l. + B.m.) (M)	96.33	68.33	84.00	18.50	546.67	456.67	380.00	11.37	28.43
S (N) + (C) (M)	81.00	47.33	120.00	17.50	423.33	366.67	310.00	9.50	23.75
P.l. (N) + (P.l. + NC) (M)	95.33	63.33	91.00	18.17	520.00	446.67	380.00	10.70	26.75
P.l. (N) + (P.l. + B.m.) (M)	88.00	52.33	112.00	17.50	466.67	400.00	333.33	10.32	25.80
P.l. (N) + (C) (M)	77.33	47.00	133.33	17.17	410.00	346.67	270.00	9.00	22.50
B.m (N) + (P.l. + NC) (M)	93.00	55.00	91.33	18.00	513.33	423.33	373.33	10.63	26.58
B.m (N) + (P.l. + B.m.) (M)	91.00	54.33	92.67	17.83	466.67	410.00	370.00	10.62	26.55
B.m (N) + (C) (M)	88.00	49.33	118.33	17.50	433.33	370.00	313.33	9.75	24.38
C (N) + (P.l. + NC) (M)	74.00	44.33	143.33	16.17	400.00	310.00	236.67	8.47	21.18
C (N) + (P.l. + B.m.) (M)	70.00	38.33	144.00	16.17	363.33	316.67	230.00	8.17	20.43
C (N) + (C) (M)	90.00	53.33	101.00	17.83	456.67	410.00	353.33	10.37	25.93
Untreated	68.33	35.33	150.00	13.50	350.00	296.67	200.00	6.92	17.30
CD (0.05)	9.57	5.47	18.97	1.59	42.02	31.67	34.71	0.92	-

S – Solarization, N – Nursery treatment, M – Main field treatment, P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans*, NC – Neem cake, Carb – Carbosulfan

field. The treatments, *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) (55.00), *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) (54.33), *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) (52.33), *B. macerans* (N) + carbosulfan (M) (49.33) were as equally effective as the chemical, carbosulfan both in the nursery and main field. This revealed the efficacy of the integration of bioagents as nursery treatment and combination of bioagents and organic amendment as main field treatment in improving the number of marketable tubers in *S. rotundifolius*. Statistically similar effect was observed among treatment combinations of solarization (N) + carbosulfan (M), *P. lilacinus* (N) + carbosulfan (M) and carbosulfan (N) + (*P. lilacinus* + neem cake) (M) with mean marketable number of tubers of 47.33, 47.00 and 44.33 respectively.

Considering the total weight of tubers per plant, all the treatments except carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (N) (363.33 g) showed significant variation compared to the untreated (350.00 g). The treatment combination, solarization (N) + (*P. lilacinus* + neem cake) (M) gave statistically same effect as that of solarization (N) + (*P. lilacinus* + *B. macerans*) (M) and *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) while *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) was on par with solarization (N) + (*P. lilacinus* + *B. macerans*) (M) and *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M). These four treatments showed significant superiority over the chemical carbosulfan (456.67 g) with mean tuber weight ranging from 513.33 to 560.00 g. The treatments, *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) and *B. macerans* (N) + carbosulfan (M) were as equally effective as carbosulfan nursery and main field application in improving the weight of tubers per plant giving mean tuber weight ranging from 433.33 to 466.67 g. Statistically similar effect was observed among solarization (N) + carbosulfan (M) (423.33 g), *P. lilacinus* (N) + carbosulfan (M) (410.00 g) and carbosulfan (N) + (*P. lilacinus* + neem

T_1 - Solarization (Nursery) + (*P. lilacinus* + neem cake) (main field)
T_2 - Solarization (Nursery) + (*P. lilacinus* + *B. macerans*) (main field)
T_{12} - Carbosulfan (Nursery) + (Carbosulfan) (main field)
T_{13} - Untreated

Plate 9. Effect of integration of selected treatments from nursery and main field on the yield of *S. rotundifolius*

cake) (M) (400.00 g). These treatments were found to be inferior to carbosulfan application both in the nursery and main field (Plate 9).

All the treatments except carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) (316.67 g) and carbosulfan (N) + (*P. lilacinus* + neem cake) (M) (310.00) showed significant superiority compared to the untreated (296.67 g) in improving marketable weight of tubers. The highest yield was recorded by solarization (N) + (*P. lilacinus* + neem cake) (M) (490.00 g). The effect of treatment combination, solarization (N) + (*P. lilacinus* + *B. macerans*) (M) was statistically on par with *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) with mean marketable tuber weight of 456.67 and 446.67 g respectively. These three treatment combinations exhibited significant superiority over the chemical in improving the marketable tuber weight per plant. The effect of the treatment combinations, *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) (423.33 g), *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) (410.00 g) and *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) (400.00 g) were as equally effective as the application of chemical carbosulfan both in nursery and main field (410.00 g). The above treatment combinations exhibited significant superiority over the other treatments *viz.*, *B. macerans* (N) + carbosulfan (M), solarization (N) + carbosulfan (M) and *P. lilacinus* (N) + carbosulfan (M) with mean weight of marketable tubers of 370.00, 366.67 and 346.67 g respectively (Table 30).

Significantly higher size (diameter) of tuber was observed in solarization (N) + (*P. lilacinus* + neem cake) (M) treatment (18.83 cm) and it was statistically on par with all the other treatment combinations except *P. lilacinus* (N) + carbosulfan (M) (17.17 cm), carbosulfan (N) + (*P. lilacinus* + neem cake) (M) (16.17 cm), carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) (16.17 cm) and untreated (13.50 cm) giving mean size of 17.50 to 18.50 cm. In the case of number of tubers per kg also the above treatment combinations were as equally effective as the chemical

application both in the nursery and main field except *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) (112.00) and *B. macerans* (N) + carbosulfan (M) (118.33) with 82.33 to 101.00 tubers per kg (Table 30).

The yield (tuber weight) per plot (2 x 2 m) in different treatments revealed that there was statistically significant variation between different treatments and untreated (6.92 kg). Among the treatments, the effect of solarization (N) + (*P. lilacinus* + neem cake) (M) (11.50 kg) was statistically on par with solarization (N) + (*P. lilacinus* + *B. macerans*) (M) (11.37 kg), *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) (10.70 kg), *B. macerans* (N) + *P. lilacinus* + neem cake) (M) (10.63 kg), (*B. macerans*) (N) + (*P. lilacinus* + *B. macerans*) (M) (10.62 kg) with significant superiority over the chemical treatment, carbosulfan in nursery and main field (10.37 kg). The per ha yield in these treatments ranged from 26.55 to 28.75 tonnes. The same trend was observed in yield in terms of edible portion weight also (370.00 to 396.67 g). In the case of per plot yield, the treatment combinations, *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) (10.32 kg), *B. macerans* (N) + carbosulfan (M) (9.75 kg) and solarization (N) + carbosulfan (M) (9.50 kg) were as equally effective as the chemical application both in nursery and main field but inferior to the above five treatments. Treatment combinations of *P. lilacinus* (N) + carbosulfan (M) (9.00 kg), carbosulfan (N) + (*P. lilacinus* + neem cake) (M) (8.47 kg) and carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) (8.17 kg) were found to be equally effective in improving the yield per plot and these three exhibited significant superiority over the untreated. With respect to edible portion weight, *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) (333.33 g) was as equally effective as the chemical, carbosulfan application in nursery and main field (353.33 g). The effect of *B. macerans* (N) + carbosulfan (M) and solarization (N) + carbosulfan (M) was statistically on par and significantly superior to *P. lilacinus* (N) + carbosulfan (M) and carbosulfan (N) + (*P. lilacinus* + neem cake) (M)

which were on par. The mean weight of edible portion of tubers in the above treatments ranged from 236.67 to 313.33 g (Table 30).

4.4.3.3 Nematode Population Characteristics

The results relating to the effect of integration of selected nursery and main field treatments on the population characteristics of *M. incognita* are presented in Tables 31 and 32. The initial population was uniform in the different plots and the larval population of *M. incognita* ranged from 250 to 270 per 250 g soil.

Nematode Population in Soil

The results relating to the effect of integration of selected treatments from nursery and main field treatments on the population build up of nematodes in coleus rhizosphere two, four and five MAT are presented in Table 31. All the treatments showed significant superiority in reducing the population buildup of *M. incognita* in soil at two, four and five MAT compared to the untreated.

The decrease in population level in the plots showed statistically significant variation. Analysis of the data on nematode population assessed at ~~2~~ two (12.33 / 250 g soil) and four MAT (15.00 / 250 g soil) revealed that mean population of *M. incognita* was lowest in solarization (N) + (*P. lilacinus* + neem cake) (M) treated plots and was significantly superior to all the other treatments. Other treatment combinations in the order of effectiveness in reducing the nematode population were solarization (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) and *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M). The above four treatment combinations showed significant superiority over the chemical, carbosulfan application in nursery and main field at two, four and five MAT.

Table 31 Effect of integrated application of selected treatments from nursery and main field on the population characteristics of *M. incognita* in *S. rotundifolius* at the time of harvest (mean of three replications)

Treatments	Population of nematodes in				
	Soil (250 g)			Root (5 g)	Tuber (10 g)
	2 MAT	4 MAT	5 MAT		
S (N) + (P.l. + NC) (M)	12.33 (3.64)	15.00 (3.99)	25.00 (5.09)	1.00 (1.38)	0.33 (1.14)
S (N) + (P.l. + B.m.) (M)	18.33 (4.39)	28.00 (5.39)	30.00 (5.57)	1.67 (1.63)	8.67 (3.07)
S (N) + (C) (M)	55.00 (7.48)	55.00 (7.48)	47.00 (6.92)	22.33 (4.83)	58.33 (7.70)
P.l. (N) + (P.l. + NC) (M)	22.33 (4.83)	33.33 (5.85)	32.33 (5.77)	3.00 (1.99)	18.33 (4.39)
P.l. (N) + (P.l. + B.m.) (M)	45.00 (6.78)	49.33 (7.09)	43.33 (6.66)	15.67 (4.06)	44.33 (6.73)
P.l. (N) + (C) (M)	41.67 (6.53)	58.33 (7.70)	51.00 (7.21)	25.00 (5.09)	61.00 (7.87)
B.m (N) + (P.l. + NC) (M)	25.00 (5.09)	35.00 (6.00)	33.00 (5.83)	8.33 (3.05)	20.00 (4.56)
B.m (N) + (P.l. + B.m.) (M)	38.00 (6.24)	45.33 (6.80)	40.00 (6.40)	13.33 (3.76)	28.30 (5.41)
B.m (N) + (C) (M)	51.33 (7.21)	51.67 (7.25)	45.00 (6.78)	18.33 (4.39)	51.33 (7.22)
C (N) + (P.l. + NC) (M)	43.00 (6.63)	60.00 (7.81)	54.33 (7.44)	28.67 (5.44)	71.67 (8.52)
C (N) + (P.l. + B.m.) (M)	55.00 (7.48)	61.67 (7.91)	58.33 (7.70)	31.67 (5.71)	84.33 (9.24)
C (N) + (C) (M)	44.33 (6.73)	48.00 (7.00)	42.33 (6.58)	14.33 (3.90)	38.67 (6.30)
Untreated	183.33 (13.57)	213.33 (14.63)	196.67 (14.05)	79.00 (8.94)	121.00 (11.04)
CD (0.05)	(0.52)	(0.45)	(0.52)	(0.59)	(0.62)

S – Solarization, N – Nursery treatment, M – Main field treatment, P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans*, NC – Neem cake, Carb – Carbosulfan, MAT – Months after treatment

Figures in parenthesis are after $\sqrt{x + 1}$ transformation

At two MAT, the effect of *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) was statistically on par with solarization (N) + (*P. lilacinus* + *B. macerans*) (M) and *B. macerans* (N) + (*P. lilacinus* + neem cake) (M), while at four MAT the treatment combinations of solarization (N) + (*P. lilacinus* + *B. macerans*) (M) established its superiority but the other 2 treatment combinations were statistically on par. The mean population of *M. incognita* in the above treatments ranged from 18.33 to 35.00 per 250 g soil. The effect of *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M), carbosulfan (N) + carbosulfan (M), *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) and *B. macerans* (N) + carbosulfan (M) was statistically on par and significantly superior to solarization (N) + carbosulfan (M) (55.00), *P. lilacinus* (N) + carbosulfan (M) (41.67), carbosulfan (N) + (*P. lilacinus*+ neem cake) (M) (43.00) and carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) (55.00) with mean larval number of 38.00 to 51.33 per 250 g soil. The same trend was observed at four MAT also with mean population of *M. incognita* ranging from 45.33 to 61.67 per 250 g soil. At the time of harvest (five MAT), the effect of treatments *viz.*, solarization (N) + (*P. lilacinus* + neem cake) (M) (25.00) and solarization (N) (*P. lilacinus* + *B. macerans*) (M) (30.00) was statistically on par and significantly superior to all other treatments. The treatment combinations, *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) (32.33) was statistically on par with *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) (33.00) and was significantly superior to application of carbosulfan both in the nursery and main field (42.33). The treatment combinations, *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M), *B. macerans* (N) + carbosulfan (M) and solarization (N) + carbosulfan (M) were as equally effective as application of carbosulfan both in the nursery and main field with mean larval population of 40.00 to 47.00 per 250 g soil. The treatment combinations of *P. lilacinus* (N) + carbosulfan (M), carbosulfan (N) + (*P. lilacinus* + neem cake) (M) and carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) were statistically on

par with mean number of 51.00, 54.33 and 58.33 *M. incognita* per 250 g soil respectively.

Nematode Population in Root

The larval population estimated from the roots varied significantly in different treatments compared to the untreated. The mean population of larvae in the root samples ranged from one to 31.67 per five g root as against 79.00 in untreated. Significantly lower number of nematodes was observed in solarization (N) + (*P. lilacinus* + neem cake) (M) treated plants (1.00) and it was statistically on par with solarization (N) + (*P. lilacinus* + *B. macerans*) (M) (1.67). The next best treatment *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) (3.00) was significantly different from *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) (8.33). These four treatments showed significant superiority over the chemical treatment in reducing the number of larvae per root. *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) and *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) were found as equally effective as carbosulfan application in the nursery and main field with mean number of larvae ranging from 13.33 to 15.67 per five g root. Treatment combinations of *B. macerans* (N) + carbosulfan (M), solarization (N) + carbosulfan (M), *P. lilacinus* (N) + carbosulfan (M), carbosulfan (N) + (*P. lilacinus* + neem cake) (M) and carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) also showed statistically significant superiority over the untreated in reducing the *M. incognita* population in root with mean numbers ranging from 18.33 to 31.67 per five g root (Table 31).

Nematode Population in Tuber

Statistical analysis of the data at the time of harvest showed significant variation between different treatments and untreated in reducing the number of larvae (Table 31). Among the effective treatments, highest significant reduction was obtained in solarization (N) + (*P. lilacinus* + neem cake) (M) (0.33 *M. incognita* per 10 g tuber). The treatment

combination, solarization (N) + (*P. lilacinus* + *B. macerans*) (M) (8,67) was significantly different from all other treatments and it was followed by *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) (18.33) and *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) (20.00) and the effect of these two was statistically on par. *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) (28.30) also showed significant difference and these five treatments exhibited significant superiority over the chemical carbosulfan (38.67) revealing that the integration of nursery treatment with bioagents and main field treatment with combination of bioagents and neem cake was highly effective in protecting the tubers from nematode infestation. The treatment *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) (44.33) was as equally effective as the chemical and was statistically on par with *B. macerans* (N) + carbosulfan (N) (51.33). The effect of solarization (N) + carbosulfan (M) was statistically on par with *P. lilacinus* (N) + carbosulfan (M) showing significant superiority over carbosulfan (N) + (*P. lilacinus* + neem cake) (M) and carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) with mean number of larvae ranging from 58.33 to 84.33 per 10 g tuber.

Root-knot Count

The mean number of galls on the roots (root-knot count) at the time of harvest showed drastic reduction due to the application of various nursery and main field treatments in an integrated manner. The results are presented in Table 32. Among the effective treatments, solarization (N) + (*P. lilacinus* + neem cake) (M), solarization (N) + (*P. lilacinus* + *B. macerans*) (M) and *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) treatments were statistically on par with mean number of 0.33, 1.00 and 1.33 root-knots per five g root respectively. Application of *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) (2.00) and *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) (2.33) was also highly effective in reducing entry of nematodes in roots and was statistically on par. The gall index was minimum (0.33) in solarization (N) + (*P. lilacinus* + neem cake)

Table 32 Effect of integrated application of selected treatments from nursery and main field on the population characteristics of *M. incognita* in *S. rotundifolius* at the time of harvest (mean of three replications)

Treatments	Number of root-knots in 5 g root	Root-knot index	Number of females in 5 g root	Number of egg masses in 5 g root	Number of eggs per egg mass
S (N) + (P.l. + NC) (M)	0.33 (1.14)	0.33	0.67 (1.24)	0.33 (1.14)	14.00 (3.84)
S (N) + (P.l. + B.m.) (M)	1.00 (1.38)	0.33	1.33 (1.47)	0.67 (1.24)	37.33 (6.18)
S (N) + (C) (M)	13.67 (3.83)	3.00	11.00 (3.46)	3.33 (2.06)	123.33 (11.15)
P.l. (N) + (P.l. + NC) (M)	1.33 (1.47)	0.67	2.00 (1.66)	0.67 (1.24)	59.00 (7.74)
P.l. (N) + (P.l. + B.m.) (M)	8.33 (3.05)	2.00	6.67 (2.76)	3.33 (1.99)	93.33 (9.69)
P.l. (N) + (C) (M)	17.67 (4.31)	3.67	6.00 (2.63)	2.33 (1.82)	133.33 (11.58)
B.m (N) + (P.l. + NC) (M)	2.00 (1.72)	1.00	2.67 (1.87)	1.33 (1.49)	59.00 (7.74)
B.m (N) + (P.l. + B.m.) (M)	2.33 (1.82)	1.00	3.67 (2.13)	3.00 (1.99)	65.67 (8.16)
B.m (N) + (C) (M)	11.67 (3.56)	2.67	8.00 (2.96)	5.00 (2.21)	120.00 (10.99)
C (N) + (P.l. + NC) (M)	20.00 (4.58)	4.33	11.00 (3.46)	7.33 (2.87)	151.67 (12.35)
C (N) + (P.l. + B.m.) (M)	22.67 (4.86)	4.67	12.33 (3.64)	10.00 (3.31)	196.67 (14.05)
C (N) + (C) (M)	7.67 (2.92)	1.67	5.67 (2.57)	3.33 (2.06)	84.00 (9.21)
Untreated	50.67 (7.19)	5.00	52.67 (7.32)	42.33 (6.58)	385.00 (19.65)
CD (0.05)	(0.52)		(0.71)	(0.58)	(0.86)

S – Solarization, N – Nursery treatment, M – Main field treatment, P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans*, NC – Neem cake, Carb – Carbosulfan

Figures in parenthesis are after $\sqrt{x + 1}$ transformation

(M) and solarization (N) + (*P. lilacinus* + *B. macerans*) (M) treatments. All these treatments showed significant superiority over the chemical, carbosulfan in reducing the root-knot count. The treatment, *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) (8.33) was statistically on par with the chemical treatments, carbosulfan (N) + carbosulfan (M) (7.67) and *B. macerans* (N) + carbosulfan (M) (11.67) in reducing the number of root-knot per five g root. Solarization (N) + carbosulfan (M) was as equally effective as that of *P. lilacinus* (N) + carbosulfan (M) while carbosulfan (N) + (*P. lilacinus* + neem cake) (M) was statistically on par with carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) with mean number of root-knot ranging from 13.67 to 22.67 per five g root.

Number of Females

Analysis of the data on the number of females per five gram root sample revealed that there was statistically significant variation between different treatments in the main field and untreated (52.67) and the results are presented in Table 32. Significantly lower population was observed among the treatment combinations of solarization (N) + (*P. lilacinus* + neem cake) (M), solarization (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) and *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) with mean number of females of 0.67, 1.33, 2.00 and 2.67 per five g root respectively. *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + carbosulfan (M) and *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) was found as equally effective as the chemical carbosulfan application in the nursery and main field with mean number of females ranging from 3.67 to 6.67 per five g root. The effect of treatments *B. macerans* (N) + carbosulfan (M), carbosulfan (N) + (*P. lilacinus* + neem cake) (M), solarization (N) + carbosulfan (M) and carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) was statistically on par with mean female number of 8.00, 11.00, 11.00 and 12.33 respectively.

Number of egg masses

All the treatments in the main field showed significant superiority over the untreated (42.33) in reducing the number of egg masses per five g root. Among the effective treatments, solarization (N) + (*P. lilacinus* + neem cake) (M), solarization (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M) and *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) were statistically on par with mean number of 0.33 to 1.33 egg masses per five g root. *P. lilacinus* (N) + carbosulfan (M), *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M) and solarization (N) + carbosulfan (M) were observed to be as equally effective as the chemical carbosulfan application both in the nursery and main field (3.33) in reducing the number of egg masses per five g root, the values being 2.33, 3.00, 3.33 and 3.33 respectively. The effect of *B. macerans* (N) + carbosulfan (M) (5.00) was significantly superior to carbosulfan (N) + (*P. lilacinus* + neem cake) (M) (7.33) and carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) (10.00) treatment combinations in reducing the number of egg masses (Table 32).

Number of Eggs per Egg mass

All the treatments significantly reduced the number of eggs per egg mass compared to the untreated (385.00). Highest reduction was observed in solarization (N) + (*P. lilacinus* + neem cake) (M) (14.00) and it showed significant difference compared to the treatment, solarization (N) + (*P. lilacinus* + *B. macerans*) (M) (37.33). These two treatments exhibited significant superiority over the chemical, carbosulfan (N) + carbosulfan (M) (84.00 eggs per egg mass). The next effective ones were *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) and *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M). They were on par with mean egg number of 59.00, 59.00 and 65.67 respectively and were significantly superior to the chemical treatment, carbosulfan (N) + carbosulfan (M). *P. lilacinus* (N) + (*P. lilacinus* + *B. macerans*) (M)

Table 33. Effect of integrated application of selected treatments from nursery and main field on the quality parameters of *S. rotundifolius* tubers after harvest (mean of three replications)

Treatments	Protein (g / 100 g dry weight of tuber)	Percentage change of protein over the untreated	Starch (g / 100 g dry weight of tuber)	Percentage increase of starch over the untreated	Sugar (g / 100 g dry weight of tuber)	Percentage increase of sugar over the untreated	Crude fibre (g / 100 g dry weight of tuber)	Percentage change of crude fibre over the untreated
S (N) + (P.l. + NC) (M)	8.77	+3.91	18.05	14.53	3.76	36.73	1.34	+47.25
S (N) + (P.l. + B.m.) (M)	8.14	-3.55	17.98	14.09	3.74	36.00	1.24	+36.26
S (N) + (C) (M)	8.23	-2.49	16.95	7.55	3.24	18.55	1.07	+17.58
P.l. (N) + (P.l. + NC) (M)	8.42	-0.24	17.18	9.01	3.72	35.27	1.25	+37.36
P.l. (N) + (P.l. + B.m.) (M)	8.27	-2.01	16.62	5.46	3.30	20.00	1.22	+34.07
P.l. (N) + (C) (M)	8.39	-0.59	16.61	5.39	3.17	15.27	0.61	-32.96
B.m (N) + (P.l. + NC) (M)	8.34	-1.18	16.68	5.84	3.63	32.00	1.20	+31.87
B.m (N) + (P.l. + B.m.) (M)	8.44	-	17.23	9.33	3.45	25.45	1.34	+47.25
B.m (N) + (C) (M)	7.75	-8.18	17.21	9.20	3.44	25.09	1.20	+31.87
C (N) + (P.l. + NC) (M)	7.62	-9.72	16.46	4.44	2.92	6.18	0.73	-19.80
C (N) + (P.l. + B.m.) (M)	8.06	-4.50	16.40	4.06	2.82	2.55	0.95	+4.40
C (N) + (C) (M)	7.25	-14.1	17.62	11.80	3.48	26.55	1.30	+42.86
Untreated	8.44	-	15.76	-	2.75	-	0.91	-
CD (0.05)	0.32	-	0.56	-	0.35	-	0.27	-

S – Solarization, N – Nursery treatment, M – Main field treatment, P.l. – *Paecilomyces lilacinus*, B.m. – *Bacillus macerans,* NC – Neem cake, Carb – Carbosulfan

treatment was as effective as the chemical, carbosulfan (N) + carbosulfan (M) with mean number of 93.33 eggs per egg mass. *B. macerans* (N) + carbosulfan (M) was statistically on par with solarization (N) + carbosulfan (M) and *P. lilacinus* (N) + carbosulfan (M) and these three treatment combinations were found to be significantly superior to carbosulfan (N) + (*P. lilacinus* + neem cake) (M) (151.67) and carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M) with mean number of eggs ranging from 133.33 to 196.67 per egg mass (Table 32).

4.4.3.4 Quality Parameters

The protein, starch, sugar and crude fibre content of the tubers of *S. rotundifolius* under different treatments are presented in Table 33. The data revealed that there was significant variation in the quality parameters of tubers among the different treatments.

Significantly higher protein content was observed in tubers of solarization (N) + (*P. lilacinus* + neem cake) (M) treated plants (8.77 g per 100 g dry weight of tuber) and was statistically on par with *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M) (8.44) and untreated control plants (8.44). In the case of starch, the effect of solarization (N) + (*P. lilacinus* + neem cake) (M) (18.05 g per 100 g dry weight of tuber) was statistically on par with solarization (N) + (*P. lilacinus* + *B. macerans*) (M) (17.98 g per 100 g dry weight of tuber) and carbosulfan (N) + carbosulfan (M) (17.62 g per 100 g dry weight of tuber). The treatment combinations, *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M), *B. macerans* (N) + carbosulfan (M), *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M), solarization (N) + carbosulfan (M) and *B. macerans* (N) + (*P. lilacinus* + neem cake) (M) were statistically on par with 5.84 to 9.33 per cent increase over the untreated. In the case of sugar and crude fibre also, maximum content was recorded in solarization (N) + (*P. lilacinus* + neem cake) (M) treatment combinations with 36.73 and 47.25 per cent increase over the untreated respectively. The treatment combinations,

solarization (N) + (*P. lilacinus* + *B. macerans*) (M), *P. lilacinus* (N) + (*P. lilacinus* + neem cake) (M), *B. macerans* (N) + (*P. lilacinus* + neem cake) (M), carbosulfan (N) + carbosulfan (M), *B. macerans* (N) + (*P. lilacinus* + *B. macerans*) (M). *B. macerans* (N) + carbosulfan (M) were as equally effective as solarization (N) + (*P. lilacinus* + neem cake) in improving sugar content. The percentage increase over the untreated in the above treatments ranged from 25.09 to 36.73 per cent.

In the case of crude fibre content, all the treatment combinations except carbosulfan (N) + (*P. lilacinus* + *B. macerans*) (M), carbosulfan (N) + (*P. lilacinus* + neem cake) (M), *P. lilacinus* (N) + carbosulfan (M) were equally effective with more than 18.00 per cent increase over untreated.

4.4.3.5 Re-isolation of Bioagent from Roots and Rhizosphere

Re-isolation of *P. lilacinus* from the rhizosphere recorded 52 colony forming units (cfu) in rose bengal agar and 40 cfu in potato dextrose agar at 10^{-3} dilution. In the case of *B. macerans*, there were 25 colony forming units in 10^{-6} dilution.

Discussion

5. DISCUSSION

Vegetables are invaluable components of our daily diet. Tubers are one group of vegetables that contribute a major part in the South Indian menu. Coleus (*Solenostemon rotundifolius*) is an important minor tuber crop grown extensively as a vegetable in most of the homestead gardens of Kerala and Tamil Nadu. Root-knot nematode, *M. incognita* is an exhausting pest causing astronomic loss to this crop. The information available on the loss in yield and biochemical changes of coleus tubers due to *M. incognita* infestation is very meagre. Hence in the present study, crop loss was assessed at four levels (5000, 1000, 500 and 100 J_2) of *M. incognita* population in micro plots to establish the pest status of *M. incognita* and to estimate the extent of loss due to various levels of the population. This is of paramount importance in the development of pest management strategy. The viability of infested tubers, loss in storage and biochemical changes due to *M. incognita* infestation during storage were also studied. These problems revealed the need for evolving an eco-friendly strategy for managing *M. incognita* associated with *S. rotundifolius*. For achieving this, field trials for managing nematodes in nursery and main field were conducted using bioagents (*Paecilomyces lilacinus*, *Bacillus macerans* and *Pochonia chlamydosporia*), organic amendment (neem cake), soil solarization, hot water treatment of tubers and their combinations. The resistance reaction of the varieties / lines / accessions, a major component in integrated nematode management strategy was also taken care of, in this study. The effective treatments and treatment combinations, selected from the nursery and main field were evaluated in the field in an integrated manner using the resistant variety. The results on the above aspects were assessed in terms of improvement in biometric characters (plant height, number of leaves and branches, plant spread and leaf area index), yield in terms of number of tubers (total and marketable),

weight of tubers (total, marketable and edible portion weight, number of tubers per kg and per plot yield, reduction in population characteristics (number of larvae in soil, root and tuber, root-knot count, number of females and egg masses and average number of eggs per egg mass) of *M. incognita* and quality parameter of coleus tubers (protein, starch, sugar and crude fibre content).

5.1 ESTIMATION OF CROP LOSS DUE TO *M. INCOGNITA*

Among the tuber crops in India, only coleus has attracted more attention as far as nematode problems are concerned. Root-knot nematode infestation in coleus was reported from Kerala by Sathyarajan *et al.* in 1966. The galls on coleus roots are very big and pronounced and *M. incognita* damage often leads to crop failure. The infested tubers swell in size with irregular surface and cracking of the skin. When the infestation is severe rotting occurs even before harvest. Infested tubers rot after harvest and rarely reach market (Mohandas *et al.*, 1988). Thus in this study, the crop loss under micro plot as well as storage condition was undertaken to assess the damage potential.

5.1.1 Under Micro Plot Condition

The results on the crop loss studies presented in 4.1.1.1 revealed that inoculation of *S. rotundifolius* with different levels of *M. incognita* exhibited statistically significant reduction in biometric characters of plants from one month after inoculation (MAI) onwards when compared to uninoculated. There was significant reduction in plant height from three MAI to five MAI (tuberisation stage) at the lowest inoculum level of 100 J_2. During the second and third month, there was significant reduction (24.24 and 14.44 per cent respectively) in height of plants at 500 J_2 level. The effect of 500 and 1000 J_2 levels, was statistically on par in reducing the height of plants at one, two, three and five MAI. Highest reduction (37.78 to 45.45 per cent) was recorded by 5000 J_2 inoculated plants from one MAI to harvest (five MAI). The percentage reduction in plant height over

the uninoculated ranged from 11.65 to 38.83, 9.85 to 45.45, 9.63 to 43.32, 14.52 to 37.78 and 12.60 to 42.91 during the first, second, third, fourth and fifth month after inoculation respectively at various inoculum levels ranging from 100 to 5000 under micro plot condition. Similar reduction in plant height due to *M. incognita* infestation in *S. rotundifolius* was reported by Sosamma (1988). Preliminary study conducted by her under pot culture condition revealed 2.00 to 25.00, 7.00 to 30.00, 6.00 to 20.00, 11.00 to 20.00 and 12.00 to 25.00 per cent reduction in height of plants from one to five MAI respectively at various inoculum levels ranging from 100 to 10,000 J_2. In this study, increased reduction in height of plants was noticed which could have been due to the natural condition that prevailed in the microplots and also the varietal difference of *S. rotundifolius*. Haseeb *et al.* (1999) reported significant reduction in plant height of *Ocimum sanctum* at an initial inoculum level of 500 *M. incognita* juveniles and above. The percentage reduction was 12.97, 23.04, 32.59 and 40.96 at 500, 1000, 2000 and 4000 J_2 levels respectively. Kumar (2004) reported statistically significant reduction (17.00 to 25.00 per cent) in height of plants of *Plumbago rosea* at 10000 J_2 level of *M. incognita* six months after inoculation onwards. The expression of reduction in height of plumbago plants in later stage of the crop may be due to the sturdy nature of the plant and presence of phenolic coating prevalent in roots. Moreover, *S. rotundifolius* plants are very susceptible to *M. incognita* infestation even at the lowest inoculum level of 100 J_2 because of the presence of soft tender roots and arrangement of cells in the cortical and stelar region.

The lowest inoculum level (100 J_2) reduced the number of leaves from two MAI onwards. Significant reduction in number of leaves was observed in 500 J_2 inoculated plants at one MAI. At the initial stages of growth of plants (one, two and three MAI), the effect of 1000 and 500 J_2 levels was statistically on par. However, at the final stage of the crop (four and five MAI), the effect of all the levels was statistically independent. The highest reduction in number of leaves was observed in

5000 J_2 inoculated plants with 15.67 to 47.16 per cent reduction over the uninoculated at one MAI to harvest. The percentage reduction in number of leaves over the uninoculated was 3.76 to 26.17, 4.79 to 15.67, 7.67 to 23.54, 18.81 to 43.56 and 26.37 to 47.16 at first, second, third, fourth and fifth month after inoculation respectively in various inoculum levels ranging from 100 to 5000 J_2. Similar findings on reduction in number of leaves were reported by several authors (Sosamma, 1988; Nalinakumari *et al.*, 1995; Kumar, 2004). They found 10.00 to 88.00, 57.00 to 68.00 and 16.00 to 29.00 per cent reduction in leaf number in coleus, betelvine and chethikoduveli respectively. The variation in reduction might be due to the difference in the physiology of plants.

In the case of number of branches, in the initial stages of growth of plants (one and two MAI) there was statistically significant reduction of 16.38 and 14.36 per cent respectively at the lowest inoculum level of 100 J_2. The effect of the levels, 500 and 1000 J_2 was statistically on par in reducing the number of branches at one, two and five MAI while it showed significant variation at three and four MAI. Highest reduction (33.00 to 47.00 per cent over uninoculated) was recorded by the plants inoculated with 5000 J_2. The percentage reduction observed was 16.38 to 42.24, 14.36 to 47.34, 5.73 to 40.84, 4.82 to 45.34 and 6.12 to 33.06 at various inoculum levels ranging from 100 to 5000 J_2 in one, two, three, four and five MAI respectively. Kumar (2004) reported 24.00 per cent reduction in number of branches of *P. rosea* at 100 J_2 inoculum level at the time of harvest.

Regarding the plant spread, the lowest inoculum level (100 J_2) was found detrimental for the growth of *S. rotundifolius* plants showing statistically significant reduction from one to five MAI. There was 15.61 to 43.90, 16.17 to 44.68, 13.74 to 45.91, 14.81 to 41.75 and 10.52 to 42.11 per cent reduction in plant spread over the uninoculated at one, two, three, four and five MAI respectively at various inoculum levels ranging from 100

to 5000 J_2. The effect of 500 and 1000 J_2 was statistically on par in reducing the plant spread at one, four and five MAI, while at two and three MAI all the levels was statistically independent. The highest reduction of 41.75 to 45.91 per cent over the uninoculated was recorded by 5000 J_2 inoculated plants from one to five MAI. The reduction in plant spread increased with increase in initial inoculum level. There has been no earlier report on this type of observations in coleus and related crops.

There was statistically significant reduction in leaf area in the lowest inoculum level of 100 J_2 onwards from the initial stage of the crop to harvest. The percentage reduction in leaf area ranged from 15.90 to 29.88, 19.69 to 36.32, 20.95 to 36.87 and 37.86 to 61.73 per cent at two, three, four and five MAI respectively over the uninoculated. The effect of 500 and 1000 J_2 was statistically on par giving 25.00 to 33.00 per cent reduction over the uninoculated from two to four MAI. At the time of harvest, the effect of all the levels was statistically independent showing significant reduction in leaf area. The plants inoculated with 5000 J_2 showed highest reduction (30.00 to 62.00 per cent over uninoculated) from initial stages of growth (one MAI) to harvest (five MAI). This finding is in line with that of Haider *et al.* (1988). They reported statistically significant reduction in leaf area of turmeric at an initial inoculum level of 1000 and 10,000 J_2 of *M. incognita*. Kumar (2004) also reported 23.00 per cent reduction in leaf area of *P. rosea* at 1000 J_2 level over control (1000 J_2 + carbosulfan) revealing there was an avoidable reduction in leaf area of 23.00 per cent in *P. rosea* due to *M. incognita* infestation. In both these crops, higher level of inoculum was required to cause significant reduction in leaf area. This may be due to the difference in physiology of the root system of turmeric, chethikoduveli and coleus. Coleus being more susceptible to infection, the lowest inoculum was sufficient to cause significant reduction in leaf area.

The results presented in 4.1.1.2 revealed the effect of different levels on the yield of *S. rotundifolius*. In the case of number of tubers (total and marketable), all the four levels (5000, 1000,500 and 100) showed statistically significant variation over the untreated. The percentage reduction in the above treatments was 15.77 to 49.58 per cent and 19.13 to 61.41 per cent for total and marketable number of tubers respectively. Thus the various inoculum levels reduced the quality of tubers and was evidenced by the highest reduction in number of marketable tubers when compared to total number of tubers. No report on this type of observation was available in coleus and other related tubers.

Regarding the size of tubers, there was progressive increase in size (in terms of diameter) in response to increase in inoculum levels of *M. incognita*. This may be due to hypertrophy and giant cell formation as a result of multiple infestation in unit area of tubers. Similar observation was reported by Sosamma (1988). She observed enlargement and increase in number of giant cells and size of galls two months after inoculation of *M. incognita* in *S. rotundifolius*. These malformed tubers exhibited high volume and the diameter increased substantially in higher inoculum levels when compared to lower level (100 J_2). The results on the number of tubers required for kg weight of tuber also confirmed the effect of *M. incognita* on reducing the size of tubers. Number of tubers per kg of *S. rotundifolius* in *M. incognita* inoculated plants showed statistically significant increase from the uninoculated to various inoculum levels (5000, 1000 and 500 J_2) except 100 J_2. There was 62.00, 54.00 and 35.00 per cent increase in number of tubers over the untreated. In other studies, the weight of tubers only was considered as yield. There was no report on this kind of estimation of number of tubers per kg weight in the literature surveyed.

The tuber yield in terms of weight of tubers ranged from 290 to 425 g at different levels of inoculum as against 527.5 g in uninoculated. There

was 19.43, 28.67, 32.23 and 45.02 per cent reduction in total and 16.05, 20.99, 35.80 and 44.75 per cent reduction in marketable weight of tubers of *S. rotundifolius* at 100, 500, 1000 and 5000 levels respectively. Thus the yield of *S. rotundifolius* decreased as initial inoculum level increased from 100 to 5000 J_2.From the lowest level of 100 J_2 onwards, there was significant reduction in yield. In the case of edible portion weight also, there was significant reduction to the tune of 19.61 to 49.84 per cent in different inoculum levels. These findings are in line with that of several workers. Sosamma (1988) reported a crop loss of 92.00 per cent (in terms of fresh weight of tubers) in coleus due to root-knot nematode at an inoculum level of 10,000 *M. incognita* larvae per pot. Mohandas and Ramakrishnan (1997) reported significant reduction in tuber yield at the lowest inoculum level of 100 J_2 of *M. incognita* per plant in a related tuber crop, *Dioscorea rotundata*. Patnaik and Das (1986) reported 22.00 per cent reduction in per plant yield of coleus under pot culture condition at an inoculum level of 100 J_2. In all these cases, there was no assessment on the edible portion weight. Thus this estimation is being reported in this study.

Regarding the population of nematodes in soil, tuber and root (root-knot count and root-knot index, number of females per five g root, number of egg masses per five g root), there was a progressive increase in recovery as the initial inoculum level increased from 100 to 5000 J_2. Initial inoculation of *M. incognita* at 5000 J_2 produced maximum root-knot and root-knot index of 5.00. However the number of egg masses per g of root was also high in higher inoculum levels and the number of eggs per egg mass reduced with increasing inoculum level. This decreased fecundity in terms of eggs per egg mass with increasing levels of nematode is perhaps due to competition among nematodes for food at higher densities, sedentary nature of female and malnutrition of female. This finding was in line with that of Patel and Thaker (1988) who reported that production of eggs per egg mass had negative correlation with

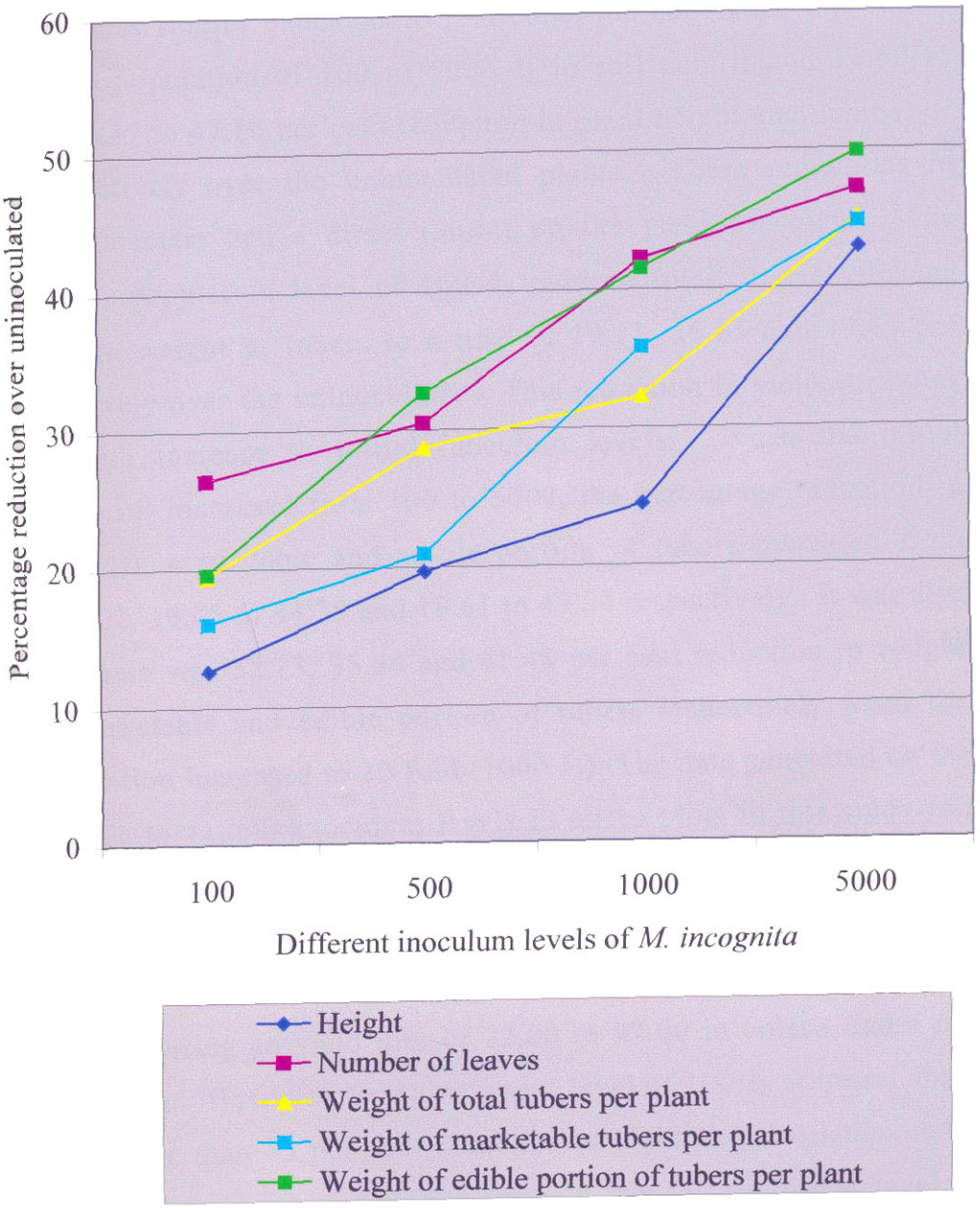


Fig. 1. Effect of different inoculum levels of *M. incognita* on the biometric characters and yield of *S. rotundifolius* at the time of harvest

increasing levels of nematode inoculum in mung bean infected by reniform nematode.

Crop loss studies under micro plot condition concluded that initial *M. incognita* population of 100 to 5000 J_2 in soil contributed 12.60 to 42.91 and 26.37 to 47.16 per cent reduction in plant height and number of leaves respectively over the uninoculated plants. These reductions in biometric characters had a direct impact on the yield of coleus. The lowest initial population level of 100 J_2 reduced total, marketable and edible portion weight of tubers to a tune of 19.13, 16.05 and 19.61 per cent respectively over the uninoculated. This reduction in yield attributes increased with increase in initial inoculum levels. When the initial population level increased from 100 to 5000, the percentage reduction in weight of total, marketable and edible portion of tubers increased from 19.43 to 45.02, 16.05 to 44.75 and 19.61 to 49.84 respectively. It was also noted that there was 32.23, 35.80 and 41.48 per cent reduction in weight of total, marketable and edible portion of tubers respectively when the initial population increased to 10 fold (1000 J_2). The data generated on the yield loss due to various inoculum levels in micro plots in this study can be used as an assessment model to forecast the expected yield loss at various initial population levels (Fig. 1). There were earlier reports by other workers on the initial population level of 100 to 10,000 juveniles of *M. incognita* causing an yield loss of 22.00 to 92.00 in coleus under pot culture condition. However, here the lowest level of 100 J_2 at initial stage contributed more than 15 per cent reduction in yield characteristics under micro plot condition. This reduction in yield due to this lowest level of *M. incognita* under micro plot condition is being reported here in coleus. Since coleus is highly susceptible to *M. incognita*, this study also highlighted the necessity of recommending proper management strategies at an initial population level of 100 J_2 per 250 g soil sample onwards.

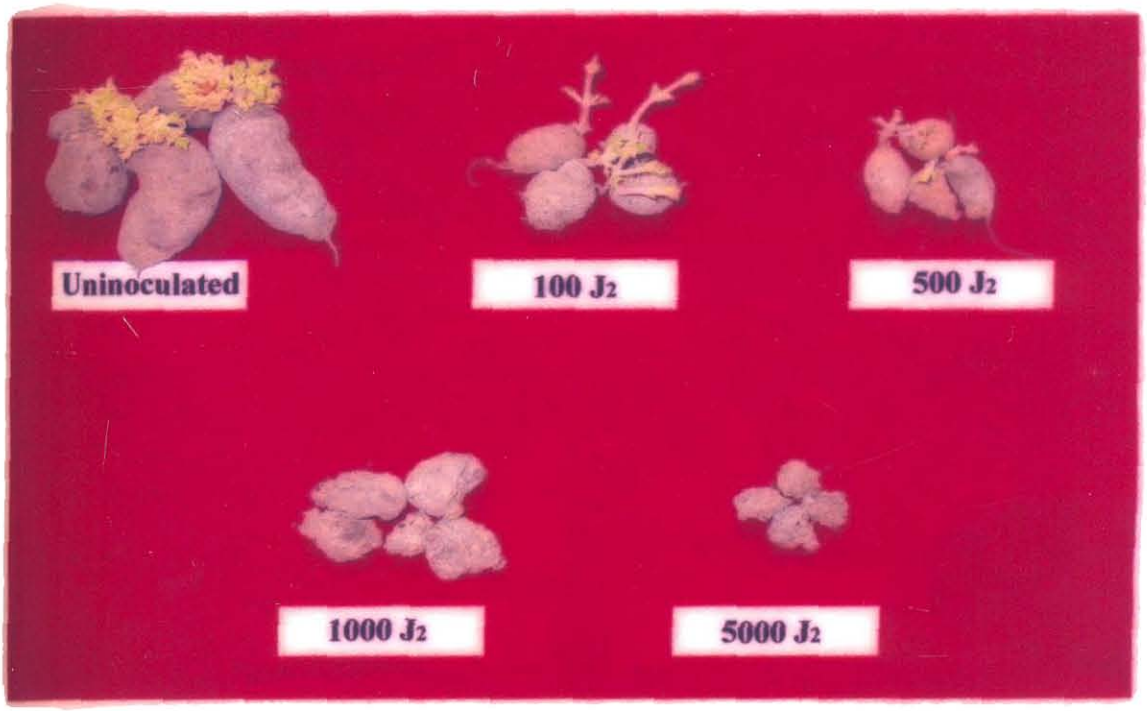


Plate 3. Effect of different levels of *M. incognita* on the germination of *S. rotundifolius* tubers three months after storage

Plate 4. Effect of different levels of *M. incognita* on the vigour of *S. rotundifolius* plants 15 days after germination

5.1.2 Crop Loss Under Storage Condition

The data presented in 4.1.2 showed that there was significant reduction in weight of tubers at different intervals of storage. The tubers from 5000 J_2 inoculated plants when stored, started rotting with a black discolouration around the female nematode within the tuber. This discolouration extended towards the interior of the tuber and the tissues became soft and turned to watery liquid with bad odour. The entire tuber gets deteriorated leaving the outer skin intact 30 days after storage (Plate 3). The tubers collected from 1000 J_2 inoculated plants get deteriorated 45 days after storage. The uninfected tubers from the uninoculated plants showed a weight loss of 12.50 per cent, 90 days after storage. This loss in weight of tubers may be due to the loss in moisture content of tubers. Generally in storage, the moisture content advocated for tubers ranged from 10.00 to 15.00 per cent only.

The percentage reduction of tuber weight in 500 and 100 J_2 inoculated plants was 96.85 and 86.80 per cent respectively at 90 DAS. The results reported here is in agreement with that of Mohandas and Ramakrishnan (1998). They reported that during storage, tubers heavily infested started rotting, while less infected tubers shrunk and developed more prominent galls. The heavily infested tubers suffered rapid weight loss compared to healthy and less infested tubers.

Thus, *M. incognita* can be included as a storage pest of coleus in addition to a field pest. The total loss due to this nematode infestation includes the field loss together with storage loss. The results of the study also emphasized the need for adoption of prophylactic measures of control from 100 J_2 onwards in order to make the tubers fully fit for consumption and marketing.

5.1.2.1 Germination and Growth Characters of Tubers after Storage

The germination percentage of tubers from 500 and 100 J_2 inoculated plants showed significant reduction of 42.37 and 7.47 per cent over the uninfected healthy tubers (cent per cent) as described in 4.1.2.1. The plants raised from the tubers collected from experimental plots inoculated with 100 and 500 J_2 showed significant reduction in vigour which was assessed in terms of biometric characters (Plate 3). The percentage reduction in plant height, number of leaves, number of branches, plant spread and leaf area index ranged from 13.11 to 45.45, 6.79 to 31.75, 11.54 to 54.90, 10.67 to 48.13 and 19.13 to 36.84 per cent at one to three months after planting. A similar type of study was reported by Singh (1977). He found out that seed germination and seedling emergence were inversely correlated with the increasing *M. incognita* population in the case of cauliflower, brinjal and tomato. Significant reduction in germination of greengram seeds (Prasad, 1981) and red beet seeds (Pathak and Keshari, 2000) was recorded at a population of 500 nematodes per kg of unsterilized soil. Reduction in growth characters of red beet when 50 juveniles of *M. incognita* were inoculated to soil. From this, it can be attributed that in coleus, the reduction in germination and vigour of plants raised from the nematode infested tubers may be due to the easy passage and subsequent growth of soil fungi and other weak pathogenic soil microflora inside the developing tissues through the injuries made by the nematodes.

5.2 ESTIMATION OF BIOCHEMICAL CHANGES DUE TO *M. INCOGNITA* INFESTATION

Results presented in 4.2 revealed that there was variation in protein content in terms of g per 100 g dry weight of tuber. The increase in protein content of tubers in different levels of inoculum ranged from 12.94 to 14.42 per cent. The increase in protein production may be due to the operation of defense mechanism of the plant and the rate of production

depends on the mode of parasitism of nematodes. This finding was in line with that of Tayal and Agarwal (1982), Arya and Tiagi (1982) and Paulson and Webster (1972). They reported increase of protein in infested cells of brinjal, carrot and tomato respectively. In carrot galls, besides the giant cells and nematodes, the adjacent parenchyma, cambium, sieve tubes, the cells lining the secretory ducts and lateral meristem were found to be rich in protein. Paulson and Webster (1972) also reported increased protein synthesis in hypersensitive cells in tomato galls. The altered protein metabolism in diseased tissue with high protease activity and increased level of soluble proteins and amino acids can be understood from the fact that host proteins are proteolytically broken down into easily assimilable forms of amino acids. The proteases are secreted by the nematode into the host tissue for such a proteolytic degradation. Released free amino acids may further synthesize new host proteins. Pathogens have been reported to produce proteolytic enzymes (Matsubara and Feder, 1970) which are often present in diseased tissue.

The starch content of tubers decreased (6.32 to 33.33 per cent at 100 to 5000 J_2) with increase in inoculum level of *M. incognita*. This result is in agreement with that of Mohandas *et al.* (1988) who reported that the percentage of starch on fresh weight basis showed two per cent reduction in infested tubers compared to 16.00 per cent in control. Tayal and Agarwal (1982) also reported reduction in starch content of diseased plants of *Solanum melongena* infested by *M. incognita* (59.00 per cent). The increased amylase activity with decreased starch level in diseased tissue can be attributed to the fact that the amylase, one of the component of cell starch is hydrolysed into easily assimilable simple sugars, such as maltose by the increased amylase activity resulting into low contents of starch. This observation suggests that amylase is secreted by the nematode. This was already reported by Orion and Bronner (1973). They reported localized strong amylase activity and very little starch within the giant cells of the tomato galls.

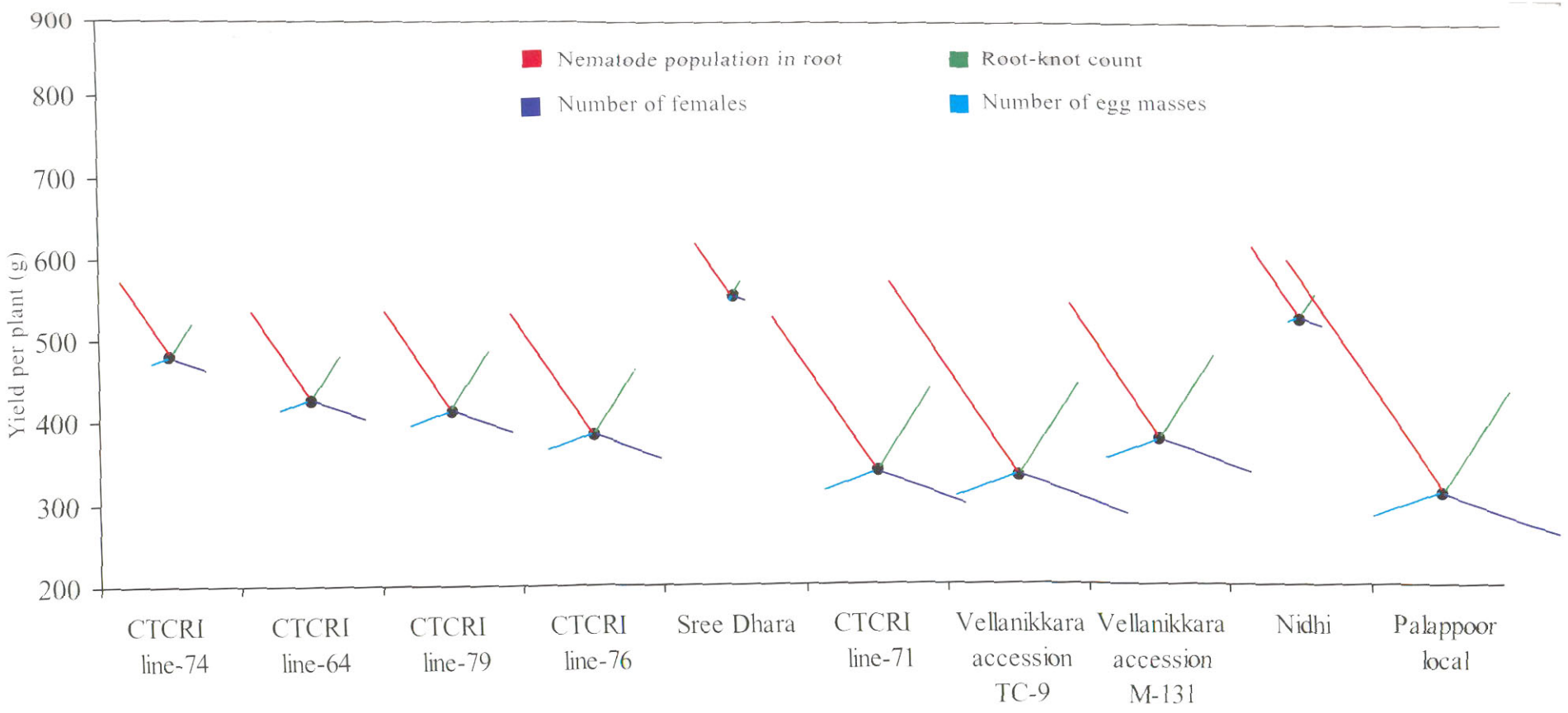


Fig. 2. Reaction of different varieties / lines / accessions of *S. rotundifolius* against *M.incognita* in yield and nematode population characteristics

The rate of production of sugar was also less in *M. incognita* infested coleus tubers. Highest reduction of 17.47 per cent was recorded in 5000 J_2 level while it was 17.20 per cent at 1000 J_2 level. This finding occurred with that of Singh *et al.* (1978), Tayal and Agarwal (1982) and Upadhyay and Banerjee (1986). They reported decrease in total sugar in brinjal, egg plant and chickpea respectively. The possible reason for the decrease of sugar content may be due to the fact that root-knot nematode either secretes some hydrolyzing enzymes or induces the production of hydrolyzing enzymes in the host which brings about conversion of stored form of sugars into its utilizable form. Roy (1979) reported the localization of invertase in the oesophagus and the intestine of the nematode parasite and suggested the possibility of its secretion by the nematode into the host tissue resulting in changed carbohydrate metabolism during the course of host parasite interaction.

In the case of crude fibre content also, there was significant reduction with increase in inoculum level and the percentage reduction over the tubers collected from uninoculated plants varied from 18.99 to 62 .03 per cent. The reduction in crude fibre content (21.30 per cent) in seeds of groundnut variety TPT-3 by *Tylenchorhynchus brevilineatus* infestation was already reported by Naidu *et al.* (2000). Here in this study this may be due to poor absorption and storage of nutrients by infested plant roots.

5.3 SCREENING FOR VARIETAL RESISTANCE

The results on population characteristics of nematodes are presented in Fig. 2. Though all the varieties / lines / accessions exhibited galling, some degree of resistance was expressed by the variety Sree Dhara with 89.00 per cent lesser number of galls when compared to susceptible check, Palapoor local. Based on the nematode multiplication in soil, root and tuber, production of females, number of egg masses per root and number of eggs per egg mass, the reaction of the variety Sree Dhara

Table 34 Ranking of different varieties / lines / accessions based on biometric characters, yield and reduction in *M. incognita* population

Treatments	Biometric characters					Yield					Reduction in nematode population								Rank
	Plant height	Number of leaves	Number of branches	Plant spread	Leaf area index	Total number of tubers / plant	Total number of marketable tubers / plant	Weight of tubers / plant	Weight of marketable tubers/ plant	Weight of edible portion of tubers / plant	Nematode population in soil	Nematode population in tuber	Nematode population in root	Root-knot count	Number of females	Number of egg masses	Number of egg/ egg masses	Overall performance	
CTCRI line – 74	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
CTCRI line – 64	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
CTCRI line – 79	5	5	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5.1	5
CTCRI line – 76	6	6	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5.9	6
Sree Dhara	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CTCRI line – 71	7	7	7	7	7	7	7	8	7	7	7	7	8	7	7	7	7	7.1	7
Vellanikkara accession–TC 9	9	9	9	8	9	9	8	9	9	9	9	9	9	9	9	9	9	8.9	9
Vellanikkara accession–M 131	8	8	8	9	8	8	9	7	8	8	8	8	7	8	8	8	8	8.0	8
Nidhi	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Palappoor local	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10

was statistically independent and better than other varieties, lines and accessions. The number of larvae (root and tuber), number of females, number of egg masses per root and number of eggs per egg mass were the lowest in Sree Dhara and the reaction of this variety was significantly different from others. Thus some degree of resistance was exhibited by the variety Sree Dhara towards nematode multiplication. The resistance reaction in carrot, brinjal, ginger and african yam cultivars against *M. incognita* was already reported by Arya and Tiagi (1982), Ravichandra *et al.* (1988), Eapen *et al.* (1998) and Mohandas *et al.* (1998) respectively. They reported moderately resistant varieties / cultivars against *M. incognita* with a root-knot index ranging from 1 to 1.5, while in this study the moderately resistant variety Sree Dhara recorded a root-knot index of one.

The potential of Sree Dhara to resist the root-knot nematode attack was directly reflected in the growth and vigour of the plant expressed in terms of biometric characters and yield. Regarding the biometric characters and yield, the variety Sree Dhara performed better than the other entries but was statistically on par with variety Nidhi and CTCRI-74 in some characters. But in overall ranking, Sree Dhara ranked first (Table 34). With respect to the quality parameters of the tubers such as protein, starch, sugar and crude fibre content also, the variety Sree Dhara exhibited better performance compared to others. In this study, the level of total sugar and starch content decreased with increase in infestation. The susceptible check, Palappoor local recorded lowest content of total sugar and starch, while least reduction of the above contents was observed in moderately resistant variety Sree Dhara. This finding was supported by Tayal and Agarwal (1982). They reported 23.00 and 59.34 per cent reduction in total sugar and starch content of brinjal seedlings (variety Pusa Purple Long) respectively by *M. incognita* infestation. The same trend was also obtained in crude fibre content in this study. This observation corroborated the finding of Naidu *et al.* (2000) in groundnut.

They reported that maximum crude fibre content was observed in seeds of the nematode disease resistant variety of groundnut (TPT-3) infested by *T. brevilineatus*. The lowest reduction in total sugar, starch and crude fibre contents in Sree Dhara may be due to the least infestation by *M. incognita* or avoidance of nematodes by the variety because of the resistant traits of the variety. The variety Sree Dhara also showed minimum multiplication of nematodes in soil, root and tubers, production of females, number of egg masses and eggs per egg mass. Based on the ability to resist nematodes and comparatively higher yield, Sree Dhara was selected as a component in the ensuing integrated nematode management experiments in coleus.

5.4 FIELD EXPERIMENTS ON MANAGEMENT OF *M. INCOGNITA*

5.4.1 Under Nursery Condition

The results presented in Fig. 3 revealed that soil solarization (150 guage LDPE film for 15 days) and bioagents (*P. lilacinus* and *B. macerans*) @ 30 g m^{-2} effectively reduced the population of nematodes in soil and root. The effect of soil solarization was significantly superior to all other treatments in reducing the nematode population in soil (87.57 per cent reduction over untreated). Several workers reported the efficacy of soil solarization in reducing the nematode population in soil (Patel and Patel, 1998; Jiji *et al.*, 2000 and Reddy *et al.*, 2001). Soil solarization of nursery beds using low density polyethylene film during summer season increased soil temperature by 9.5, 8.4 and 4.9°C at 5, 10 and 15 cm soil depths respectively over non-solarized beds (Patel and Patel 1998). The effect of soil solarization and *P. lilacinus* was on par in reducing the root-knot count and nematode population in root. The efficacy of *P. lilacinus* in reducing the gall index of tomato was reported by Goswami *et al.* (1998). *P. lilacinus* was also found effective against *M. incognita* on potato and tomato, *Globodera rostochinensis* on potato, *Tylenchulus semipenetrans* on citrus and *Rotylenchulus reniformis* in tomato and egg plant (Reddy

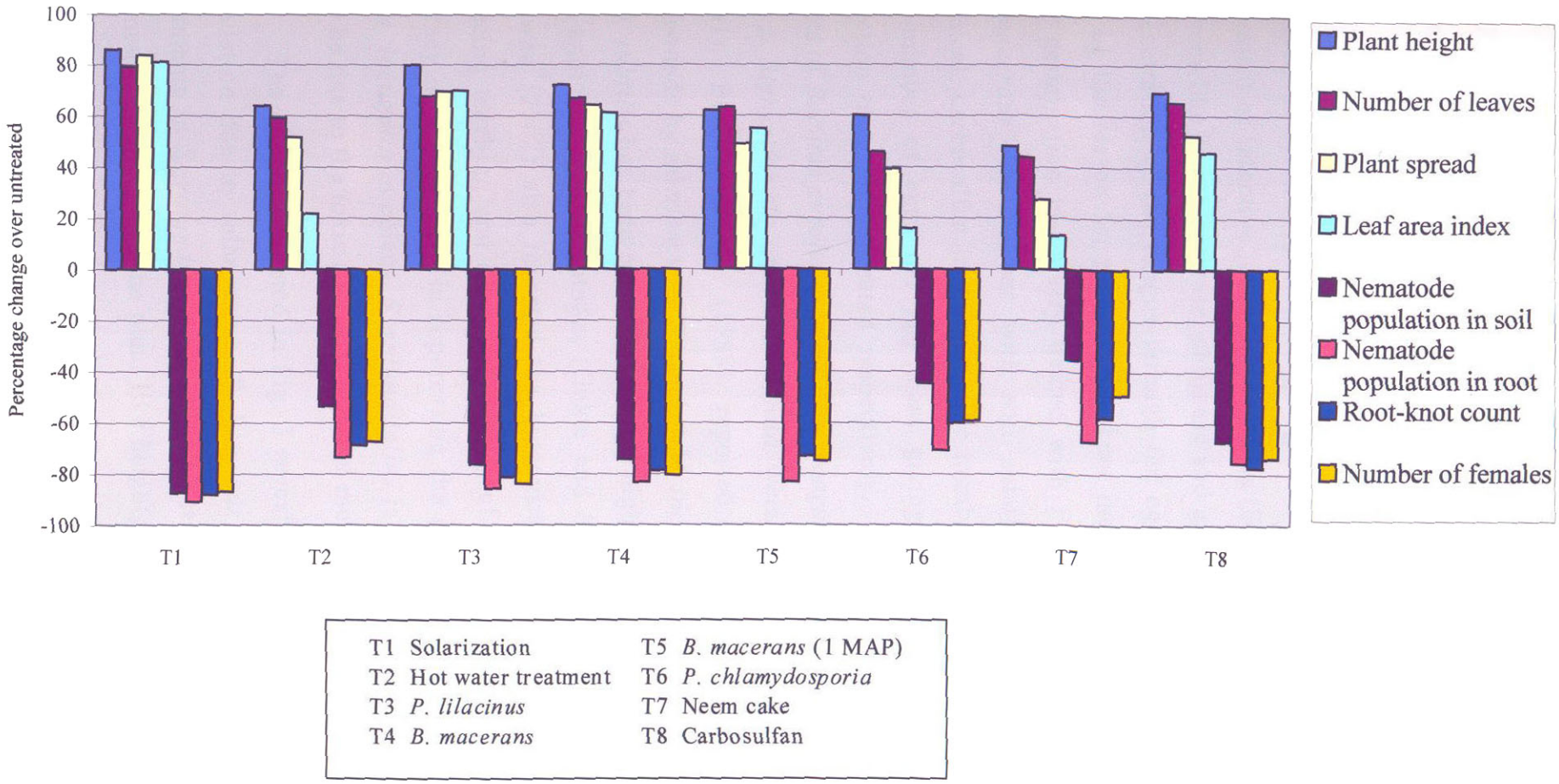


Fig. 3. Effect of different treatments in the nursery on the biometric characters and population of *M. incognita* in *S. rotundifolius* (1 MAP)

and Khan, 1988 and 1989). The nematicidal action was attributed to fungal metabolites or antibiotics produced by *P. lilacinus*. The fungus has been reported to produce peptidal antibiotics *viz.*, lilacinin, leucinostatin and paecilotoxin (Arai *et al.*, 1973; Mikami *et al.*, 1989). Acetic acid produced abundantly during fungal growth in liquid medium inhibited movement of infective juvenile nematodes (Dijian *et al.*, 1991). The lytic enzymes like serine protease, chitinase and gluco amylase also play a role in penetration of the fungus through the egg shell of nematodes. These may be the reason for reduced root-knot index in coleus plants 30 days after germination in nursery treated with *P. lilacinus*. The potential of *B. macerans* was on par with soil solarization and better than the chemical, carbosulfan in reducing the number of females in root system and number of eggs per egg mass giving 80.44 and 90.78 per cent reduction over the untreated respectively. The ovicidal and larvicidal effects of *Bacillus pumilis*, *B. subtilis, B. coagulans, B. circulans, B. macerans* and *B. licheniformis* on *M. incognita* were already reported by Sheela (1991). Becker *et al.* (1988) reported production of nematicidal compounds by rhizobacteria to control *M. incognita*. Non-cellular extracts of *B. subtilis* has been reported to cause high degree of larval mortality of root-knot and cyst nematodes (Gokte and Swarup, 1988). Niknam and Dhawan (2002) also reported the biocontrol potential of *B. subtilis* in reducing hatching and causing mortality of *R. reniformis in vitro*. The efficacy of *B. macerans* in suppressing the number of eggs per egg mass of *M. incognita* in coleus, *S. rotundifolius* is being reported this study and may be due to the toxic effect of bacterial metabolites.

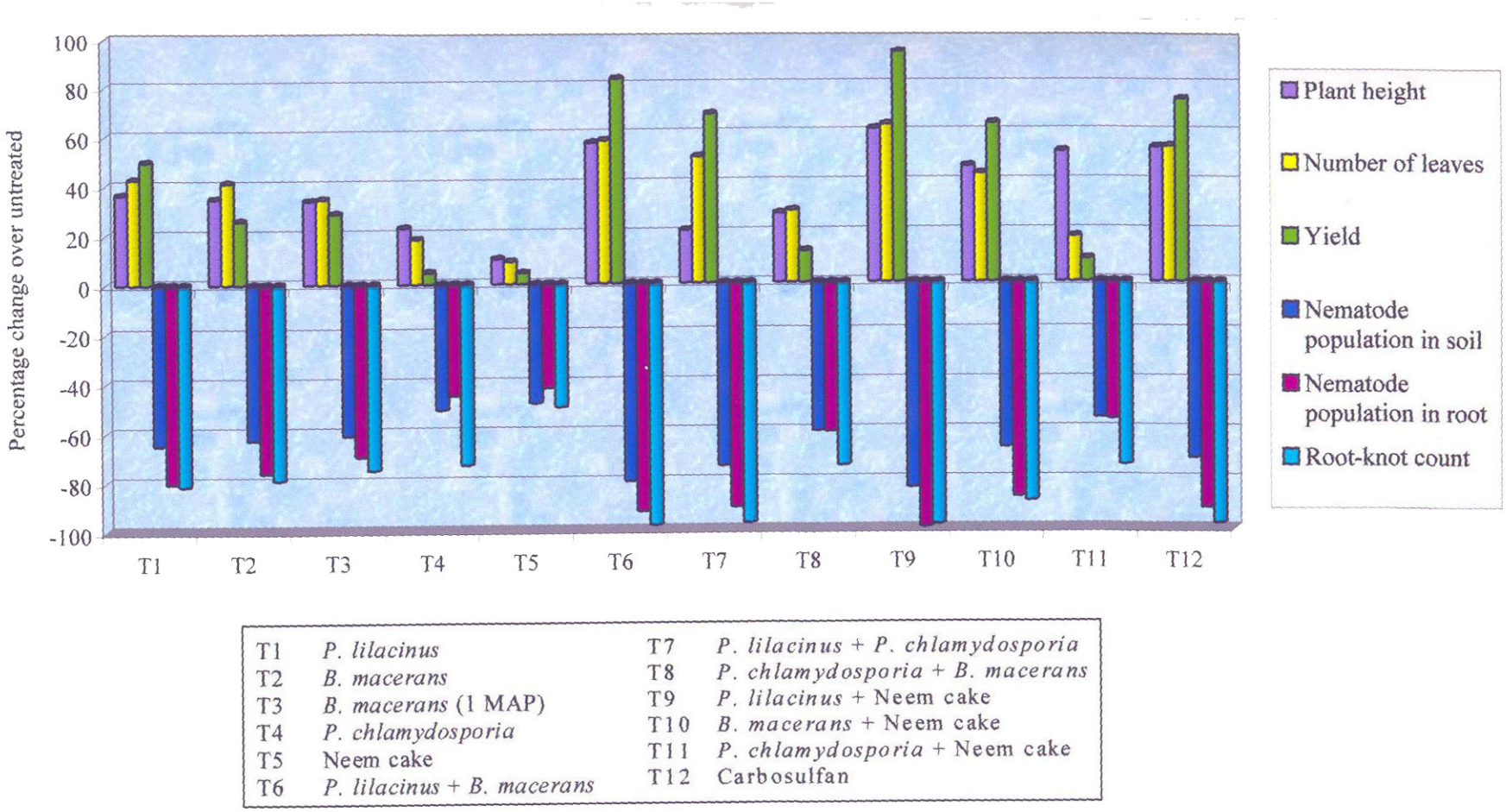
The results presented in Fig. 3 revealed the reduction in nematode population due to solarization, *P. lilacinus* and *B. macerans* as nursery treatments in *S. rotundifolius* and its effect was directly reflected in the biometric characters of the plant like height, number of leaves, number of branches, plant spread and leaf area index. Physical methods (soil solarization and hot water treatment) and bioagents (*P. lilacinus* and

B. macerans) were as effective as the recommended chemical, carbosulfan in improving plant height and number of leaves (63.95 to 85.96 and 59.21 to 79.21 per cent increase over the untreated respectively). Soil solarization was found superior to carbosulfan and other treatments in the case of improvement in plant spread. The effect of solarization (88.83 per cent increase) and *P. lilacinus* (83.33 per cent increase) was on par and significantly superior to carbosulfan and *B. macerans* which were on par and recorded same percentage increase (66.67) in number of branches. Regarding the leaf area index, significantly higher improvement was brought about by soil solarization and its effect was on par with *P. lilacinus* and *B. macerans* giving 61.14 to 81.14 per cent increase over the untreated. The effect of carbosulfan was on par with *B. macerans* (one MAP) but was inferior to soil solarization. *P. lilacinus* and *B. macerans* (at the time of planting) treatments recorded 45.71 per cent increase over the untreated. The effect of *P. lilacinus* in improving the plant growth characters was already reported by various authors (Rao *et al.*, 1998a in brinjal; Goswami *et al.*, 1998 in tomato; Sosamma and Koshy, 1995 in black pepper; Eapen and Venugopal, 1995 in cardamom; Nakat *et al.*, 1998 in betel vine). *B. macerans* was found effective against root-knot nematode in bhindi and pepper (Sheela and Venkitesan, 1992). From this study, it can be concluded that soil solarization of nursery and application of bioagents like *P. lilacinus* and *B. macerans* in the nursery are the effective treatments to manage the root-knot nematode in coleus for getting healthy and vigorous cuttings for transplanting to main field.

5.4.2 Under Main Field Condition

Results on the study to establish the efficacy of bioagents (*P. lilacinus*, *B. macerans* and *P. chlamydosporia*) and organic amendment, neem cake singly and in combination in the main field for the management of root-knot nematode associated with *S. rotundifolius* are presented in 4.4.2.

The results on periodical estimation of *M. incognita* population in soil (two, four and five MAT) revealed that the effect of *P. lilacinus* (15 g m^{-2}) + neem cake (100 g m^{-2}) and *P. lilacinus* + *B. macerans* (15 g m^{-2}) was on par and superior to all the other treatments including the chemical, carbosulfan at two, four and five MAT. From the study, carbosulfan was found to be inferior to the combination of above bioagents and organic amendment. The potential of *P. lilacinus* in combination with neem cake or *B. macerans* in reducing the nematode population was established in this study. Rao *et al.* (1997a and 1998a) reported the efficacy of neem cake suspension mixed with *P. lilacinus* spores in managing root-knot nematode in okra and brinjal respectively. The success of *P. lilacinus* in managing root-knot nematode in tuber crops (potato and carrot) was already reported by Jatala *et al.* (1980) and Sivakumar (1998). *P. lilacinus* parasitizes the eggs and egg masses of root-knot nematode by producing hydrolytic enzymes such as chitinases, endochitinases, proteases etc. The egg shell and gelatinous matrix of root-knot nematode contains chitin (Bird and Self, 1995; Spiegel and Cohn, 1985). Several authors reported the effectiveness of organic amendments (oil cakes) for the management of nematodes in various crops by releasing toxic glycosides and enhancing the growth of fungi and other antagonistic microorganisms infecting nematodes in crops, *viz.,* brinjal, (Kamalakshiamma, 1986), ginger (Sheela *et al.*, 1995) and kacholam (Nisha and Sheela, 2003). For the effective management of the nematode, the life cycle of the nematode should coincide with the application of the fungus. Neem cake acts as a suitable substrate promoting multiplication and rapid establishment of the fungus *P. lilacinus* and thereby increases the availability of the fungus to the nematode. Neem cake being a good soil conditioner, will improve the vigour of the plant also. In this study, the population reduction in the rhizosphere of the coleus plants may be due to the additive effect of the bioagent (*P. lilacinus*) and organic amendment (neem cake). In addition to the above action, the ovicidal



T1	*P. lilacinus*	T7	*P. lilacinus* + *P. chlamydosporia*
T2	*B. macerans*	T8	*P. chlamydosporia* + *B. macerans*
T3	*B. macerans* (1 MAP)	T9	*P. lilacinus* + Neem cake
T4	*P. chlamydosporia*	T10	*B. macerans* + Neem cake
T5	Neem cake	T11	*P. chlamydosporia* + Neem cake
T6	*P. lilacinus* + *B. macerans*	T12	Carbosulfan

Fig. 4. Effect of different treatments in the main field on the biometric characters, yield and population of *M. incognita* in *S. rotundifolius* at the time of harvest

effect of *P. lilacinus* adversely affected the progeny production of the nematode.

The treatment combination, *P. lilacinus* + *B. macerans* was found as equally effective as *P. lilacinus* + neem cake treatment in reducing the population of root-knot nematode in the coleus rhizosphere. Sheela *et al.* (2004) reported the potential of *B. macerans* (2 per cent solution) as dipping of cuttings + drenching in soil seven days after planting in managing root knot-nematode in coleus. The efficacy of *P. lilacinus* in combination with *B. macerans* in reducing the root-knot nematode population in coleus is being reported for the first time.

Nematode population in root was also significantly reduced by *P. lilacinus* + neem cake treatment showing its superiority over the chemical, carbosulfan. Treatment combinations, *P. lilacinus* + *B. macerans* and *P. lilacinus* + *P. chlamydosporia* were as effective as carbosulfan in reducing the number of larvae in root (more than 50 per cent reduction over the untreated). Similar trend was established by these treatments in reducing the nematode population in tuber also. The biocontrol potential of *P. lilacinus* in combination with nematode and *P. chlamydosporia* was already reported by several workers in various crops (Reddy and Khan, 1991a in acid lime and Haque *et al.*, 1997 in mungbean). Rao *et al.* (1998c) reported the effect of integration of *P. chlamydosporia* and *P. penetrans* for managing *M. incognita* in tomato. However, the efficacy of *P. lilacinus* in combination with neem cake/ *B. macerans/P. chlamydosporia* in reducing the *M. incognita* population in tuber crops has not been reported earlier.

In the case of root-knot count, *P. lilacinus* in combination with bioagents (*B. macerans* and *P. chlamydosporia*) and organic amendment (neem cake) was found as effective as carbosulfan, giving more than 97.00 per cent reduction over the untreated (Fig. 4). The effect of *P. lilacinus* and neem cake in reducing root-knot index and final population of

M. incognita was reported in gladiolus (Nagesh *et al.*, 1998b) and brinjal (Mojumder *et al.*, 2000). They reported significant increase in root-colonization, propagule density in soil and per cent infection by *P. lilacinus* and neem cake revealing the complementary effect of these two components in the sustainable management of *M. incognita*. Regarding the number of females and egg masses per root, treatment combinations of *P. lilacinus* + neem cake and *P. lilacinus* + *B. macerans* were found as effective as the chemical, carbosulfan in main field. However these two treatment combinations showed significant superiority over the chemical in reducing the number of eggs per egg mass. Integration of oil cakes with fungi resulting in increased parasitisation of eggs, colonization of roots and spore density in soil was reported by several workers (Mani and Anandam, 1989; Reddy *et al.*, 1991; Rao *et al.*, 1997a). This clearly highlighted the efficacy of oil cakes as substrates for the growth and multiplication of *P. lilacinus* resulting in increased parasitisation of eggs.

The beneficial effect of combined application of *P. lilacinus* and *P. penetrans* in suppressing the population of *M. incognita* and enhancing the growth and yield of tomato and black pepper was reported by Maheswari and Mani (1988) and Sosamma and Koshy (1995) respectively. However the efficacy of *P. lilacinus* in combination with *B. macerans* in reducing the number of females and egg masses per root in *S. rotundifolius* is being reported in this study. The nematicidal action of *P. lilacinus* and *B. macerans* reported by several workers (Arai *et al.*, 1973; Mikami *et al.*, 1989; Dijian *et al.*, 1991; Sheela, 1991). Thus the initial protection of the transplanted cuttings of *S. rotundifolius* from nematodes by the application of *P. lilacinus* in combination with neem cake or *B. macerans* will increase the establishment of coleus.

The reduction in nematode population (due to application of *P. lilacinus* in combination with either neem cake or *B. macerans*) directly

reflected on the biometric characters of the plant like height, number of leaves, number of branches, plant spread and leaf area index (4.4.2.1). The treatment combinations of *P. lilacinus* + neem cake and *P. lilacinus* + *B. macerans* showed significant superiority over the chemical, carbosulfan in the main field in improving the number of leaves and leaf area index at the final stages of the crop. The improvement in biometric characters due to the reduction in population of *M. incognita* by the action of *P. lilacinus* in combination with neem cake in the root-zone of various crops was reported by several workers (Reddy *et al.*, 1997 in tomato; Nagesh *et al.*, 1998a in tube rose; Bhat *et al.*, 1998 in chick pea). In the case of number of branches and plant spread, the effect of *P. lilacinus* in combination with either neem cake or *B. macerans* proved to be as equally effective as the chemical, carbosulfan at the final stage of the crop (three to five MAT). This finding was in agreement with that of Kumar (2004) who reported the phytotonic effect of carbosulfan and bioagents (*Glomus fasciculatum*, *Pseudomonas fluorescens* and *P. lilacinus*) in improving the biometric characters of *P. rosea*.

The improvement in biometric characters was reflected in increase in yield of coleus in terms of weight of tubers (total, marketable and edible portion) (4.4.2.2). In the case of total and edible portion weight of tubers per plant, the treatment combination of *P. lilacinus* + neem cake established its superiority over all other treatments (including the chemical, carbosulfan) giving 81.42 and 98.34 per cent increase over the untreated.

Due to *M. incognita* infestation, there was increase in the protein content in tubers (4.4.2.4) and it may be due to the altered protein metabolism in the infested tissue by host induced defense mechanism. The treatment combination of *P. lilacinus* + neem cake showed 21.93 per cent increase over the untreated in improving the starch content of tubers. The decreased starch levels in infested tubers may be due to the secretion of

amylase by the nematode, which hydrolyse the starch into easily assimilable simple sugars like maltose. This concurred with the findings of Orion and Bronner (1973).

Application of *P. lilacinus* in combination with either neem cake or *B. macerans* was found as equally effective as the chemical in improving sugar and crude fibre content of tubers. The invertase enzyme secreted by the nematode into the host tissue leads to altered carbohydrate metabolism during the course of host parasite interaction resulting in low content of sugars in infested tubers. By reducing the nematode infestation by effective treatments, the sugar content was maintained in tubers in this study.

Thus the application of bioagents (*P. lilacinus*, *B. macerans*) in combination with organic amendment (neem cake) not only reduced the nematode population but also improved the biometric characters and yield of coleus compared to carbosulfan. The tubers collected from *P. lilacinus* + neem cake treatment recorded 21.93, 37.31 and 53.76 per cent increase in starch, sugar and crude fibre content respectively over the untreated. However, in recommended chemical treatment, it was 14.32, 19.40 and 47.31 per cent respectively only. From this, it can be concluded that the integration of *P. lilacinus* and neem cake improved the quality of the tubers compared to the chemical in the main field.

5.4.3 Experiment on Integrated Management of *M. incognita*

The nematode population characteristics presented in Fig. 5 revealed that the combination of solarization in the nursery (N) and application of *P. lilacinus* + neem cake in main field (M) significantly reduced the nematode population in soil (initial to final stages of *S. rotundifolius*). The treatment combinations showed a similar trend in managing *M. incognita* population in tuber also. The effect of solarization in the nursery in reducing the soil nematode population has already been reported by several workers (Jain and Gupta, 1997a; Mahapatra and

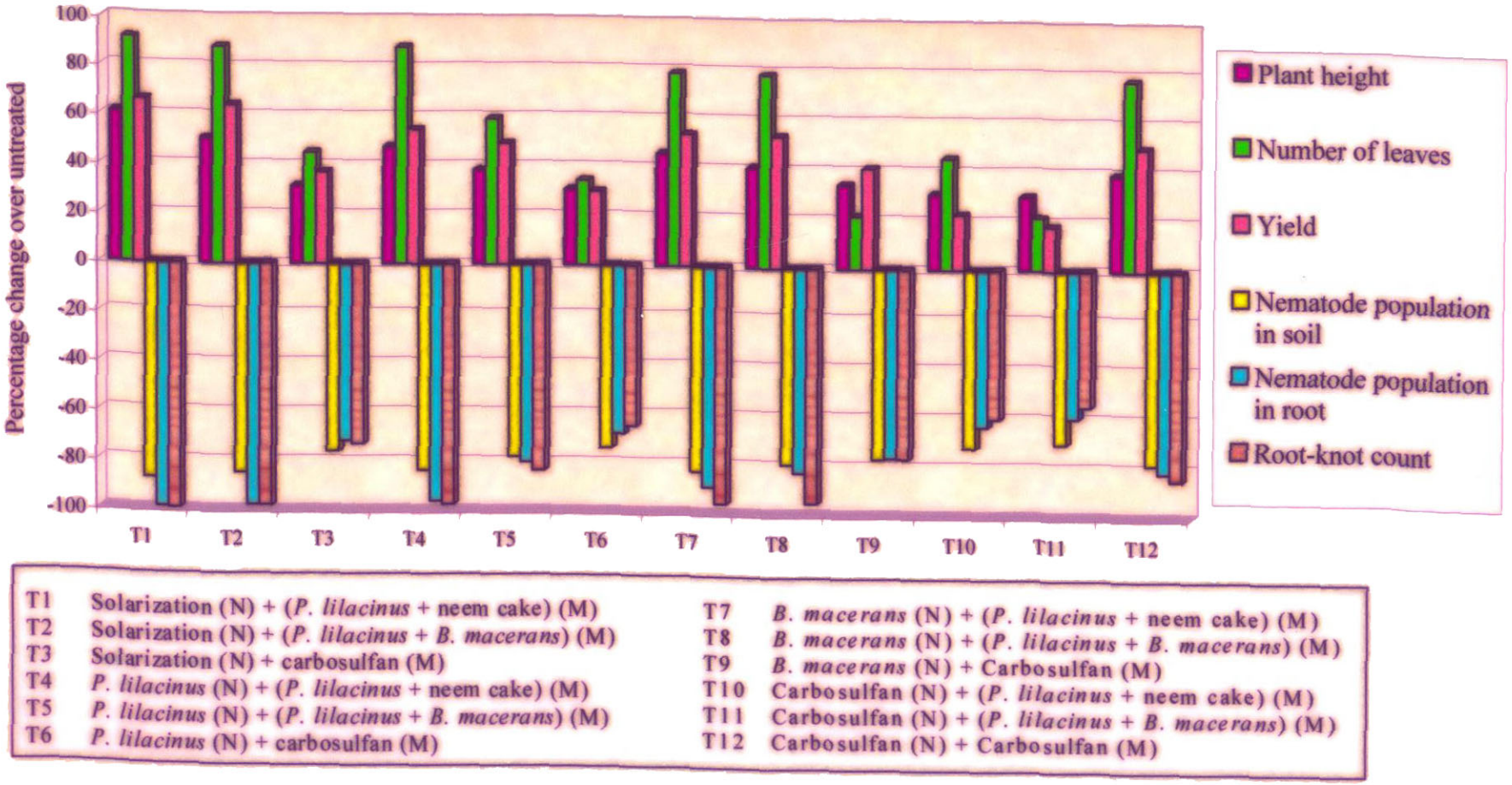


Fig. 5. Effect of application of selected treatments from nursery and main field on the biometric characters, yield and population characteristics of *M. incognita* in *S. rotundifolius* at the time of harvest

Mohanty, 2000; Hussaini *et al.*, 2001). *P. lilacinus,* an egg parasite and heavy sporulator has also been recognized as a biological control agent capable of successfully establishing in soil when introduced artificially. Several workers reported the potential of *P. lilacinus* in suppressing the population of *M. incognita* in crops *viz.*, okra (Saikia and Roy, 1994), tomato (Khan and Goswami, 2000) and brinjal (Khanna, 2000). However there was no report on the beneficial effect of *P. lilacinus* in *S. rotundifolius*. The mode of action of various fungal parasites on *M. incognita* was described by many workers. According to Morgan-Jones and Rodriguez-Kabana (1984), the reduction in *M. incognita* population was due to fungal attack on larvae or death of females before laying eggs there by reducing their fecundity. In this study, the potential of *P. lilacinus* was boosted by combining with neem cake as evidenced by the result on reduction in *M. incognita* population in soil and roots. The beneficial effect of neem cake for boosting the potential of egg parasitic fungi, *P. lilacinus* established in this study is in agreement with Tiyagi and Ajaz (2004). They reported the efficacy of combined application of *P. lilacinus* with neem cake in reducing nematode population in chickpea under field conditions. However the integration of nursery solarization and application of *P. lilacinus* and neem cake in main field for managing *M. incognita* in *S. rotundifolius* is being reported for the first time in this study. This could be due to nematicidal action of neem cake and the nematode parasitising ability of *P. lilacinus*. Solarization in the nursery along with combined application of *P. lilacinus* and *B. macerans* in main field also showed significant superiority over the chemical, carbosulfan application (both in nursery and main field). Sosamma and Koshy (1997) reported the efficacy of the fungus, *P. lilacinus* in combination with bacteria, *P. penetrans* in reducing the nematode population in black pepper. Here the beneficial effect of the treatment combination involving *B. macerans* and *P. lilacinus* in main field may be due to the additive or combined effect of both the bioagents against the root-knot nematode.

The treatment combinations, solarization (N) + (*P. lilacinus* + neem cake) (M) and solarization (N) + (*P. lilacinus* + *B. macerans*) (M) showed significant superiority over the chemical, carbosulfan application (in nursery and main field) reduced the number of eggs per egg mass. In the present study, highest reduction in eggs per egg mass was observed in solarization (N) + (*P. lilacinus* + neem cake) (M) treatment combination and it could be due to the ovicidal action of the fungus and nematicidal action of the neem cake. The better establishment of the fungus in the soil was also attributed by the addition of oil cakes. This finding was in agreement with that of several workers who reported the efficacy of *P. lilacinus* application in combination with *P. penetrans* or neem cake in managing *M. incognita* in *Vigna radiata* (Zaki and Maqbool, 1990), tomato (Reddy *et al.*, 1997) and tube rose (Nagesh *et al.*, 1998a).

The reduction in nematode population characteristics by the above treatment combinations in nursery and main field was directly reflected on the biometric characters of the plant *viz.*, height, number of leaves, number of branches, plant spread and leaf area index. Highest plant height was recorded by the combination of nursery solarization along with *P. lilacinus* + neem cake application in the main field, at two months after treatment (MAT). It showed statistically significant superiority over all other treatment combinations including the chemical, carbosulfan (in nursery and main field). In the case of leaf area index also, this treatment combination showed significant superiority over all other treatments including the chemical (three and five MAT). Soil amendment with neem cake basically a habitat management tactic, provided better conditions to the beneficial soil microflora and fauna. The physiological changes in the roots and nematicidal principles released by the decomposition of neem cake reduced and contained the nematode population in soil and contained the pathogenic effect of *M. incognita*. Increased microbial activity in the amended soil brought about increased conversion of nitrogen to nitrate form which increased the metabolic activity of plants and resulted in

improvement in growth and vigour of coleus plants. This enhanced root growth and nutrient uptake by the coleus plants was due to the suppression of nematode multiplication by the fungus. So the combined application of *P. lilacinus* and neem cake helped in improving the vigour of the plants in terms of biometric characters.

These improvements in biometric characters positively influenced the yield of coleus in terms of number and weight of tubers. The treatment combination solarization (N) + (*P. lilacinus* + neem cake) (M) established its superiority over all the other treatments including the chemical, carbosulfan both in nursery and main field, in improving the weight of marketable tubers per plant. The efficacy of nursery solarization in improving the growth characters and yield of plants was already reported in brinjal (Jiji *et al.*, 2000), tomato (Mahapatra and Mohanty, 2000) and tobacco (Hussaini *et al.*, 2001). In this study, the effect of nursery solarization and main field application of *P. lilacinus* and neem cake in improving the yield in coleus is being reported for the first time. The nematode activity was suppressed by the fungus and neem cake. The improvement of plant growth characters of the above treatment combination in coleus increased marketable number of tubers also. The effect of nursery solarization in combination with application of *P. lilacinus* plus neem cake in the main field and solarization (N) + (*P. lilacinus* + *B. macerans*) (M) were found equally effective and showed significant superiority over the chemical, carbosulfan in improving the number of marketable tubers. The effect of combined application of *P. lilacinus* and *P. penetrans* in enhancing the plant growth parameters and yield of tomato, brinjal and black pepper was already established by Maheswari and Mani (1988), Zaki and Maqbool (1990) and Sosamma and Koshy (1997) respectively. However the effect of combined application of *P. lilacinus* + *B. macerans* is being reported in this study.

The results presented in 4.4.3.4 revealed that starch, sugar and crude fibre content of tubers, increased in solarization (N) + *P. lilacinus* + neem cake (M) treatment and recorded 14.53, 36.73 and 47.25 per cent increase respectively over the untreated, whereas in the chemical treatment (both in nursery and main field) it was only 11.80, 26.55 and 42.86 per cent respectively. Nematode infested tubers showed significant reduction in sugar and starch content. Thus in maintaining the nutritional quality of tubers also, solarization (N) + (*P. lilacinus* + neem cake) (M) treatment was found to be the best.

The success of this study on integrated nematode management strategy in coleus was due to the following facts. Solarization in the nursery not only reduced the nematode population in the soil but also enhanced the tuber germination, plant establishment and plant growth parameters significantly. The healthy vigourous cuttings obtained from the solarized nursery on transplanting to the main field amended by *P. lilacinus* in combination with either neem cake or *B. macerans,* performed better. These treatment combinations were also found effective in managing nematodes in soil in the initial stages of growth of plants, improving the soil physical properties and promoting the multiplication of bioagents. It reduced the rate of reproduction of *M. incognita* in coleus root as evidenced in the result on the production of galls and egg masses in root sample and number of eggs per egg mass. The selection of a suitable variety Sree Dhara, considering the desirable attributes also contributed to this strategy. Thus based on the overall performance in reduction of nematode population in soil and root, the improvement of biometric characters and yield of coleus tubers, integration of soil solarization in nursery for 15 days with 150 guage LDPE film and main field application of *P. lilacinus* in combination with either neem cake or *B. macerans* were the best treatments for recommendation in an integrated nematode management strategy in coleus. The strategy protected the coleus crop against phytonemtodes and improved the plant growth characters, yield (64.31 to 66.18 per cent increase in per hectare weight of tubers) and population of

M. incognita (97.89 to 98.73 per cent reduction in root). These treatment combinations are environmentally safe and sustainable in nature. As nursery solarization and application of neem cake, *P. lilacinus* and *B. macerans* will not contribute to any toxic effect in soil and are not detrimental to the beneficial fauna, they can be considered as eco-friendly. Though the application of *P. lilacinus* and *B. macerans* will not afford cent per cent nematode control, the left over population in soil serves as a medium for the multiplication of the biological control agents. This will go a long way in the subsequent management of phytonematodes in a sustainable manner.

Summary

6. SUMMARY

A detailed investigation on integrated management of root-knot nematode *Meloidogyne incognita* (Kofoid and White) Chitwood infesting coleus, *Solenostemon rotundifolius* (Poir) Morton was carried out in the Department of Agricultural Entomology, College of Agriculture, Vellayani, Thiruvananthapuram during 2002-2005. The results were assessed in terms of biometric characters, yield, nematode population characteristics and quality parameters of tubers.

Microplot studies were conducted to estimate the extent of crop loss by different levels of *M. incognita* (100, 500, 1000 and 5000 J_2) in *S. rotundifolius*. Significant reduction in biometric characters (plant height, number of leaves, plant spread and leaf area index) was observed from the lowest inoculum level of 100 J_2 onwards at the time of harvest. The plants inoculated with 100 J_2 showed 9.63 to 14.52 per cent reduction in height over the uninoculated plants at tuberisation stage (three to five months after inoculation). The lowest inoculum level of 100 J_2 significantly reduced the number of leaves from two months after inoculation onwards. The percentage reduction in number of leaves over the uninoculated was 26.37 to 47.16 at the time of harvest in various inoculum levels ranging from 100 to 5000 J_2. In the case of number of branches, in the initial stages of growth of plants (one and two months after inoculation), there was statistically significant reduction of 16.38 and 14.36 respectively at 100 J_2. The lowest inoculum level of 100 J_2 was found detrimental as evidenced from the significant reduction in plant spread and leaf area index of *S. rotundifolius* plants recorded from one to five months after inoculation. Significant reduction of 10.52 to 42.11 per cent was observed in plant spread at the time of harvest in various inoculum levels ranging from 100 to 5000 J_2. In the case of leaf area index, there was 15.90 to 20.88, 19.69 to 36.32, 20.95 to 36.87 and 37.86

to 61.73 per cent reduction at two, three, four and five months after inoculation respectively at various inoculum levels ranging from 100 to 5000 J_2. In yield attributing characters also 100 J_2 was found critical. The number of total and marketable tubers showed 15.77 and 19.13 per cent reduction respectively over the uninoculated. The weight of total, marketable and edible portion of tubers decreased significantly when the inoculum level increased from 100 to 5000 J_2. The percentage reduction being 19.43 to 45.03, 16.05 to 44.75 and 19.61 to 49.84 respectively. The population of *M. incognita* estimated at the time of harvest from soil, root and tuber exhibited statistically independent effect at various inoculum levels ranging from 100 to 5000 J_2. The recovery of *M. incognita* from soil, root and tuber increased with increase in initial inoculum level. Similar trend was observed in the case of number of root-knots, females and egg masses also. Highest root-knot index of 5.00 was recorded in 5000 J_2 inoculated plants and root-knot indices in 1000, 500 and 100 J_2 levels were 4.75, 3.00 and 2.00 respectively.

Crop loss studies under storage condition revealed significant reduction in weight, germination and vigour of plants raised from tubers collected from 100 J_2 inoculated plants. The tubers collected from 5000 and 1000 J_2 inoculated plants, deteriorated 15 and 45 days after storage respectively. The weight losses in tubers were 12.50, 86.80 and 96.85 per cent in uninoculated, 100 J_2 and 500 J_2 inoculated plants respectively at three months after storage. The tubers collected from uninoculated plants showed cent per cent germination, three months after storage, while the germination percentage of tubers collected from 100 and 500 J_2 inoculated plants was only 42.37 and 7.47 respectively. There was significant reduction in vigour of plants in terms of biometric characters. The percentage reduction in plant height, number of leaves, number of branches, plant spread and leaf area index ranged from 13.11 to 45.45, 6.79 to 31.75, 11.54 to 54.90, 10.67 to 48.13 and 19.13 to 36.84 per cent at one to three months after planting.

The biochemical changes in tubers of *S. rotundifolius* infested by various levels of *M. incognita* were assessed in terms of protein, starch, sugar and crude fibre contents. The starch, sugar and crude fibre contents in tubers collected from plants inoculated with different inoculum levels were significantly reduced. The reduction being 6.32 to 33.33, 8.06 to 17.47 and 18.99 to 62.03 per cent respectively over the uninoculated in 100 to 5000 J_2 level. However, the protein content showed an increase of 12.94 to 14.42 per cent over the uninoculated in the above levels.

In order to find out a resistant variety for integrated management strategy in *S. rotundifolius* varieties/lines/accessions against *M. incognita* was carried out under pot culture condition. The biometric characters, yield and nematode population characteristics were compared with the susceptible check, Palappoor local. The variety Sree Dhara ranked first in biometric characters and yield closely followed by the variety Nidhi. The performance of variety Sree Dhara was statistically on par with Nidhi in the case of total, marketable and edible portion weight of tubers per plant. Sree Dhara, Nidhi and CTCRI line-74 were statistically on par in the production of total and marketable tubers per plant. With regard to the number of tubers per kg, the variety Sree Dhara, Nidhi and CTCRI line-74 performed equally well with mean number of 85.00, 91.00 and 93.67 tubers respectively. Thus these two varieties and the line recorded statistically less number of tubers for making one kg weight. The variety Sree Dhara showed statistically significant variation from the rest of varieties / lines / accessions in reducing the nematode population characteristics. Lowest number of larvae, females, eggmasses in root and eggs per eggmass were recorded in Sree Dhara. This variety also recorded minimum root-knot index of 1.00. Hence variety Sree Dhara was selected for the integrated nematode management study in *S. rotundifolius*.

The effect of various treatments in the nursery revealed that physical methods (soil solarization and hot water treatment) and bioagents

(*Paecilomyces lilacinus* and *Bacillus macerans*) were as effective as the recommended chemical, carbofuran in improving plant height and number of leaves. Soil solarization was superior to carbosulfan and all other treatments improving the plant spread. Regarding the leaf area index soil solarization was statistically on par with *P. lilacinus* and *B. macerans*. The percentage increase in index ranged from 61.14 to 81.14. Nursery solarization significantly reduced the population of *M. incognita* in soil (87.50 per cent over untreated) while the effect of nursery solarization was statistically on par with *P. lilacinus* in reducing the number of root-knots and larvae in root compared to the untreated. The reduction due to the above treatments were 81.25 to 88.13 in number of root-knots and 85.75 to 90.75 in larvae. However the nursery solarization showed maximum reduction in number of egg masses in root system and was significantly superior to other treatments. The effect of solarization was statistically on par with *P. lilacinus* and *B. macerans* in reducing the number of females in root (80.44 to 86.96 per cent).

The effect of various treatments in the main field condition showed statistically significant variation from untreated. The treatment combinations of *P. lilacinus* + neem cake and *P. lilacinus* + *B. macerans* established significant superiority over the other treatment combinations, carbosulfan and untreated, in improving the number of leaves and leaf area index at the final stages of the crop. The effect of these treatments were statistically on par in improving plant height, number of branches and plant spread (more than 50 per cent increases over the untreated). The treatment combination of *P. lilacinus* + neem cake showed significant superiority over the rest of the treatments in increasing the weight of total tubers per plant (81.42 per cent). The effect of treatment combinations of *P. lilacinus* + neem cake and *P. lilacinus* + *B. macerans* were statistically on par in improving the number and weight of marketable tubers per plant (more than 70 per cent). In the case of weight of edible portion of tubers, significant variation was observed between *P. lilacinus* + neem cake and

P. lilacinus + *B. macerans* treatments with 98.34 and 83.34 per cent increase over the untreated respectively. The same trend was observed in per plot yield also. The per hectare yield of above two treatments ranged from 23.93 to 25.40 tonnes as against 13.08 tonnes in untreated plots. The population of *M. incognita* extracted from soil two, four and five months after treatment and number of eggs per egg mass revealed significant variation from untreated. The lowest values were recorded in *P. lilacinus* + neem cake and *P. lilacinus* + *B. macerans* treatment combinations and the effect of these two were statistically on par. However, *P. lilacinus* + neem cake treatment combination exhibited significant superiority over all other treatments in reducing the *M. incognita* population in root (98.89 per cent) and tuber (99.25 per cent) compared to the untreated. The effect of *P. lilacinus* + neem cake was statistically on par with *P. lilacinus* + *B. macerans* and carbosulfan in reducing the number of root-knots, females and egg masses in root (89.40 to 98.72 per cent over the untreated). Thus these treatment combinations were as effective as the chemical treatment in managing nematodes.

The biochemical changes in terms of protein, starch, sugar and crude fibre content of tubers revealed that *P. lilacinus* + neem cake treatment was statistically superior in maintaining the quality of tubers. Highest starch content of 17.96 g per 100 g dry weight of tuber was recorded by *P. lilacinus* + neem cake treatment. While in the sugar and crude fibre content of tubers, the effect of *P. lilacinus* + neem cake, *P. lilacinus* + *B. macerans* and carbosulfan were statistically on par.

In the integrated nematode management trial there was statistically significant improvement in biometric characters and yield in various treatments compared to the untreated. Integration of nursery solarization and mainfield application of *P. lilacinus* along with either neem cake or *B. macerans* and nursery application of *P. lilacinus* in combination with main field treatment of *P. lilacinus* + neem cake were superior to

carbosulfan in improving the height, plant spread and leaf area index at the time of harvest. Combination of nursery solarization and main field application of *P. lilacinus* together with *B. macerans* exhibited significant superiority over the untreated in improving the weight of marketable tubers per plant. Regarding the weight of edible portion of tubers and yield per plot, the treatment combinations of nursery solarization or application of either *P. lilacinus* or *B. macerans* in the nursery along with main field application of *P. lilacinus* + neem cake or *P. lilacinus* + *B. macerans* showed significant superiority over carbofuran application (more than 50 per cent increase over the untreated). Nursery solarization plus main field application of *P. lilacinus* in combination with either neem cake or *B. macerans* significantly reduced *M. incognita* population in soil and root. Solarization in the nursery along with combined application of *P. lilacinus* and neem cake in the main field showed significant superiority over all other treatments in reducing the number of larvae ((99.73 per cent) in tuber and eggs per egg mass (96.36 per cent). The effects of nursery solarization plus main field application of *P. lilacinus* and neem cake in combination, nursery solarization plus combined application of *P. lilacinus* and *B. macerans* in the main field, nursery application of *P. lilacinus* plus combined application of *P. lilacinus* and neem cake in the main field and nursery application of *B. macerans* plus combined application of *P. lilacinus* and neem cake in the main field were on par in reducing the number of egg masses and females in root. Treatment combinations of solarization along with combined application of *P. lilacinus* with either neem cake or *B. macerans* in main field and nursery application of *P. lilacinus* along with combined application of *P. lilacinus* + neem cake (main field) showed significant superiority over the rest of treatments in reducing the number of root-knots in *S. rotundifolius* roots. Statistically comparable effect was observed among these three treatments with 99.35, 98.03 and 97.38 per cent reduction in number of root-knot over the untreated respectively.

Treatment combinations of solarization and combined application of *P. lilacinus* with either neem cake or *B. macerans* in main field were effective in maintaining protein, starch, sugar and crude fibre content of tubers compared to the rest of treatments in *S. rotundifolius* variety Sree Dhara.

Based on the above investigations the following recommendations are obtained and reported.

- There was significant reduction in biometric and yield attributing characters at the lowest level of 100 J_2 onwards under micro plot condition.
- The stored tubers collected from 5000 and 1000 J_2 inoculated plants completely deteriorated 15 and 45 days after storage.
- Heavy loss in weight of stored tubers was noticed in 100 J_2 (86.80 per cent) and 500 J_2 (96.85 per cent) inoculation.
- The germination and vigour of the plants also showed significant reduction at 100 J_2 level.
- *M. incognita* infestation resulted significant reduction in starch, sugar and crude fibre content of tubers.
- Sree Dhara was identified as *M. incognita* resistant variety.
- Solarization and application of *P. lilacinus* and *B. macerans* yielded healthy vigorous cuttings in nursery for transplantation.
- Integration of nursery solarization along with combined application of *P. lilacinus* with either neem cake or *B. macerans* in main field improved biometric characters, yield and quality parameters of *S. rotundifolius* by managing *M. incognita* population.

References

7. REFERENCES

A.O.A.C. 1969. *Official and Tentative Methods of Analysis.* Tenth edition. Association of Official Agricultural Chemists, Washington, D.C., p. 145

A.O.A.C. 1975. *Official and Tentative Methods of Analysis* Twelfth edition. Association of Official Agricultural Chemists, Washington, D.C., p. 136

Abid, M., Ehteshamul-Haque, S., Sultana, V., Ara, J., Ghraffar, A. and Maqbool, M.A. 1995. Comparative efficacy of neem cake and other organic amendments on the control of root-knot nematode in mung bean. *Pakist. J. Nematol.* 13: 103-107

Acharya, A. and Padhi, N.N. 1988. Effect of neem oil and saw dust against root-knot nematode *Meloidogyne incognita* in betel vine (*Piper betle). Indian J. Nematol.* 18: 105

Acharya, A., Dash, S.C. and Padhi, N.N. 1993. Biological control of root-knot nematode, *Meloidogyne incognita* on betel vine using parasitic fungus, *Paecilomyces lilacinus*. Nat. Symp. Recent Approaches Integrated Nematode Mgmt agric. Crops, 6-7 August 1993. Haryana Agricultural University. *Abstract* : 10

Ahmad, R., Abbas, M.K., Khan, M. A., Inam-ul-Haq-M., Javed, N. and Sahi, S.T. 1994. Evaluation of different methods of application of *Pasteuria penetrans* for the biocontrol of *Meloidogyne incognita* infesting tomato. *Pakist. J. Nematol.* 12 : 155-160

Alagumalai, K., Thiruvalluvam, M., Nagendran, N. and Ramraj, P. 1995. Effect of acid extract of neem cake on the populations build up of *Meloidogyne incognita. Environment Ecol.* 13: 275-277

Ali, S.S. 1995. Estimation of yield losses in urd bean crop due to *Meloidogyne incognita*. Nat. Symp. Recent Approaches Integrated Nematode Mgmt agric. Crops, 6-7 August 1993. Haryana Agricultural University, Hissar. *Abstract*: 20

Anith, K.N., Manomohandas, M., Jayarajan, M., Aipe, K.C. and Vasanthakumar, K. 2000. Integration of soil solarization and biological control with fluorescent *Pseudomonas* sp. for controlling bacterial wilt *Ralstonia solanacearum* Vabuuchi *et al.* of ginger. *J. Biological Control* 14: 25-29

Anitha, B. and Subramanian, S. 1998. Management of the reniform nematode, *Rotylenchulus reniformis* in tomato. *Proc. Third int. Symp. Afro-Asian Soc. Nematologists, 16-19, April 1998* (ed. Mehta, U.K.). Sugarcane Breeding Institute, Coimbatore, pp. 249-250

Antonio, H. 1988. Evaluation of losses caused by *Meloidogyne incognita* race-4 on soybean cultivar BR-4. *Nematologia Brasileira* 12: 29-34

Anver, S. and Alam, M.M. 2001. Biological control of soil nematodes associated with linseed. *Archives Phytopath. Pl. Prot.* 34: 101-109

Arai, T.Y., Mikami, K., Fukushima, T., Utsumi and Yazawa, K. 1973. A new antibiotic, leucostatin, derived from *Pencillium lilacinum*. *J. Antibiot.* Tokyo, 26: 157-161

Arya, M. and Tiagi, B. 1982. Reaction of some carrot cultivars to root-knot nematode, *Meloidogyne incognita*. *Indian J. Nematol.* 12: 397

Atu, U.G., Odurukwe, S.O. and Ogbuji, R.O. 1983. Root-knot nematode damage to *Dioscorea rotundata*. *Pl. Dis.* 67: 814-815

Barman, M. and Das, P. 1993. Effect of chemical seed dressing and organic amendment alone and its combination for root-knot nematode, *Meloidogyne incognita* management of greengram, *Vigna radiata*. Nat. Symp. Recent Approaches Integrated Nematode Mgmt agric. Crops, 6-7 August 1993, Haryana Agricultural University, Hissar. *Abstract*: 79

Barman, M. and Das, P. 1996. Effect of chemical seed dressing and organic amendment alone and in combination for the management of root-knot nematode, *Meloidogyne incognita* on greengram. *Indian J. Nematol.* 26: 72-76

Basu, S.P.S. and Sukul, N.C. 1983. Effect of root-knot nematode *Meloidogyne incognita* on the total protein, carbohydrate and lipid in roots at different growth stages of *Hibiscus esculentus*. *Indian J. Nematol.* 13: 66-70

Becker, J.O., Zaraleta-Mejia, E., Colbert, S.F., Schroth, M.N., Weinhold, A., Hancock, J.G. and Van Gundy, S.D. 1988. Effects of rhizobacteria on root-knot nematodes and gall formation. *Phytopathology* 78: 1466-1469

Bharali, A. and Phukan, P.N. 1996. Reaction of certain cucumber cultivars to root-knot nematode, *Meloidogyne incognita*. *J. agric. Sci. Soc. N.E. India* 9: 169-170

Bhargava, S. and Sharma, M.K. 2001. Assessment of yield losses and varietal screening of chilli and tomato against *Meloidogyne incognita*. *J. Mycol. Pl. Path.* 31: 238-239

Bhat, M.Y., Hisamuddin and Fazal, M. 1998. Combined application of *Paecilomyces lilacinus* and oil cakes for protection of chickpea against *Meloidogyne incognita*. *Proc. Third int. Symp. Afro-Asian Soc. Nematologists, 16-19 April 1998* (ed. Mehta, U.K.). Sugarcane Breeding Institute, Coimbatore, pp. 258-261

Bhatti, D.S. and Jain, R.K. 1977. Estimation of loss in okra, tomato and brinjal yield due to *Meloidogyne incognita*. *Indian J. Nematol.* 7: 37-41

Bird, A.F. and Self, P.G. 1995. Chitin in *Meloidogyne javanica*. *Fundamental appl. Nematol.* 18: 235-240

Bora, A. 1990. Pathogenicity and management of *Meloidogyne incognita* on greengram (*Vigna radiata.* M.Sc. (Ag.) thesis, Assam Agricultural University, Jorhat, Assam, p. 120

Cannayane, I. and Rajendran, G. 2001. Application of biocontrol agents and oil cakes for the management of *Meloidogyne incognita* in brinjal (*Solanum melongena* L.). *Curr. Nematol.* 12: 51-55

Cannayane, I. and Sivakumar, C.V. 1999. Seed treatment with *Paecilomyces lilacinus* against *Meloidogyne incognita* in blackgram and cowpea. *Int. J. trop. Pl. Dis.* 17: 121-127

Cannayane, I., Sivakumar, C.V. and Jonathan, E.I. 2004. Colonization of blackgram, cowpea, tomato and chilli roots by *Paecilomyces lilacinus* protects *Meloidogyne incognita* invasion. Nat. Symp. Paradigms Nematological Res. Biodynamic Fmg, 17-19 November 2004. Nematological Society of India, University of Agricultural Sciences, Bangalore. *Abstract*: 97

Chakrabarti, U. and Mishra, S.D. 2001. Seed treatment with neem products for integrated management of *Meloidogyne incognita* infecting chickpea. *Curr. Nematol.* 12: 15-19

Chakrabarti, U. and Mishra, S.D. 2002. Evaluation of biochemical parameters for screening resistance of chickpea cultivars against *Meloidogyne incognita. Indian J. Nematol.* 32: 26-29

Chand, R., Gill, J.S. and Yadav, B.D. 2001. Management of root-knot nematode using *Pasteuria penatrans* on the first and second subsequent tomato crop. Nat. Congr. Centenary Nematology India Appraisal Future Plans, 5-7 December 2001. Nematological Society of India, Indian Council of Agricultural Research, National Academy of Agricultural Sciences, Department of Science and Technology, Society of Plant Protection Sciences, Indian Agricultural Research Institute, New Delhi. *Abstract*: 141

Channabasappa, B.S., Krishnappa, K. and Reddy, B.M.R. 1995. Utilization of ecofriendly biological agents and biocomponents on the integrated management of *Radopholus similis* on banana. Nat. Symp. Nematode Problems India–An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26, March 1995. Indian Agricultural Research Institute, New Delhi. *Abstract*: 42

Charles, J.S.K. 1978. Studies on the nematode diseases of ginger (*Zingiber officinale* Rose). M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, p. 74

*Cobb, N.A. 1918. Estimating the nematode population of the soil. *Agric. tech. Cir. I. Bur. Pl. Ind., U.S. Dep. Agric. Washington D.C.*, p. 48

Cochran, W.G. and Cox, G.M. 1965. *Experimental Designs*. John Wiley and Sons Inc., New York, p.182

*Cuadra, R., Aguilera, C. and Perez, J.A. 1999. Effect of solarization on nematodes in disinfestation of soil for coffee nurseries. *Revista-de-Protection-Vegetal* 14: 23-26

Das, H. 1992. Crop loss assessment of lentil (*Lens esculenta*) due to *Meloidogyne incognita* and its management. M.Sc. (Ag.) thesis, Assam Agricultural University, Jorhat, Assam, p. 105

Deka, U. and Phukan, P.N. 1997. Crop loss assessment in okra due to *Meloidogyne incognita*. *J. agric. Sci. Soc. E. India* 10: 249-251

Devappa, V., Krishnappa, K. and Reddy, B.M.R. 1998. Estimation of avoidable losses in yield due to root-knot nematode *Meloidogyne incognita* in sunflower. *Indian J. Nematol.* 28: 95-96

Devarajan, K. and Rajendran, G. 2001. Effect of fungus *Paecilomyces lilacinus* (Thom.) Samson on the burrowing nematode, *Radopholus similis* (Cobb.) Thorn. in banana. *Pest Mgmt hort. Ecosystems* 7: 171-173

Devarajan, K. and Rajendran, G. 2002. Effect of fungal egg parasite, *Paecilomyces lilacinus* (Thom) Samson on *Meloidogyne incognita* in banana. *Indian J. Nematol.* 32: 78-101

Devi, G. and Das, P. 1998. Effect of different organic amendments for the management of root-knot nematode, *Meloidogyne incognita* on carrot. *Indian J. Nematol* 28: 203-207

Dijian, C.L., Pijarowski, M., Ponchet, N., Arpin, N. and Favre-Bonvin, J. 1991. Acetic acid, a selective nematicidal metabolite from culture filtrates of *Paecilomyces lilacinus* (Thom) Samson and *Trichoderma longibrachiatum* Rifari. *Nematologica* 37: 101-112

Dube, B. and Smart, G.C. Jr. 1987. Biological control of *Meloidogyne incognita* by *Paecilomyces lilacinus* and *Pasteuria penetrans*. *J. Nematol.* 19: 222-227

Dutta, K. and Haider, M.G. 2001. Response of varieties / cultivars of Raj mash (*Phaseolus vulgaris*) to *Meloidogyne incognita* race-2. Nat. Congr. Centenary Nematology India Appraisal Future Plans, 5-7 December, 2001. Nematological Society of India, Indian Council of Agricultural Research, National Academy of Agricultural Sciences, Department of Science and Technology, Society of Plant Protection Sciences, Indian Agricultural Research Institute, New Delhi. *Abstract*: 133

Eapen, S.J. 1994. Pathogenicity of *Meloidogyne incognita* on small cardamom, *Elettaria cardamomum* Maton. *Indian J. Nematol.* 24: 31-37

Eapen, S.J. and Venugopal, M.N. 1995. Field evaluation of *Paecilomyces lilacinus* and *Trichoderma* spp. in cardamom nurseries for the control of root-knot nematodes and rhizome rot disease. Nat. Symp. Nematode Problems India – An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26 March 1995. Indian Agricultural Research Institute, New Delhi. *Abstract*: 43

Eapen, S.J., Ramana, K.V., Sasikumar, B. and George, K.J. 1998. Resistance to *Meloidogyne incognita* in ginger and turmeric germplasms. *Proc. nat. Symp. Rational Approaches Nematode Mgmt Sustainable Agric., 23-25 November 1998* (eds. Dhawan, S.C. and Kaushal, K.K.). Gujarat Agricultural University, B.A. College of Agriculture, Anand. Nematological Society of India, Indian Agricultural Research Institute, New Delhi, pp. 106-109

Ekanayake, H.M.R.K. and Jayasundaram, N.J. 1994. Effect of *Paecilomyces lilacinus* and *Beauveria bassiana* on controlling *Meloidogyne incognita* on tomato in Sri Lanka, *Nematol. Medit.* 22: 87-88

Ganguly, A.K., Raman, R. and Dasgupta, D.R. 1991. Qualitative and quantitative changes in protein in cowpea inoculated with root-knot nematode, *Meloidogyne incognita* race 1. *Indian J. Nematol.* 21: 113-122

Ganguly, S. and Dasgupta, D.R. 1981. Protein patterns in resistant and susceptible tomato varieties inoculated with the root-knot nematode, *Meloidogyne incognita. Indian J. Nematol.* 11: 180-182

*Garcia, O. and Espinosa, J. 1982. Assessment of economic losses caused by *Meloidogyne* spp. on light tobacco variety Hicks-187. *Cienciay-Tecnica-en-la-Agric., Prot.-de-plantas* 5: 79-95

Gaur, H.S. and Mishra, S.D. 1990. Integrated control of nematodes in lentil with aldicarb, neem cake and seed treatment with thimet and its residual effect on the subsequent mung crop. *Indian J. Ent.* 51: 283-287

Gogoi, B.B. and Gill, J.S. 2001. Compatibility of *Pasteuria penetrans* with carbofuran and organic amendments, its effect on *Heterodera cajani. Ann. Pl. Protection Sci.* 9: 254-257

Gokte, N. and Swarup, G. 1988. On the potential of some bacterial biocides against root-knot and cyst nematodes. *Indian J. Nematol.* 18: 152-153

Gopinatha, K.V., Nagesh, M. and Gowda, D.N. 2002a. Biochemical estimation of resistance in tomato cultivars to root-knot nematode, *Meloidogyne incognita*. *Indian J. Nematol.* 32: 224-226

Gopinatha, K.V., Gowda, D.N. and Nagesh, M. 2002b. Management of root-knot nematode, *Meloidogyne incognita* on tomato using the biocontrol agent *Verticillium chlamydosporium,* neem cake, marigold and carbofuran. *Indian J. Nematol.* 32: 179-181

Goswami, B.K. and Mishra, S.D. 1993. Comparative efficacy of neem cake and carbofuran on plant parasitic nematodes infecting pea. Nat. Symp. Recent Approaches Integrated Nematode Mgmt agric. Crops, 6-7 August, 1993. Haryana Agricultural University, Hissar. *Abstract*: 23

Goswami, B.K. and Chawla, G. 2002. Different combinations of neem cake and carbofuran against *Meloidogyne incognita* on *Vigna radiata*. *Int. J. Nematol.* 12: 106-110

Goswami, B.K. and Mittal, A. 2002. Effect of some fungal bioagents on root-knot nematode, *Meloidogyne incognita* infecting brinjal. *Pakist. J. Nematol.* 20: 55-59

Goswami, B.K. and Sharma, S.B. 2001. Application of *Aspergillus terreus* and *Paecilomyces lilacinus* for the management of *Meloidogyne incognita* on tomato. *Int. J. Nematol.* 11: 270-273

Goswami, B.K., Rao, U. and Singh, S. 1998. Potential of some fungal bioagents against root-knot nematode, *Meloidogyne incognita* infecting tomato. *Proc. First nat. Symp. Pest Mgmt hort. Crops, 15-17 October 1998* (eds. Reddy, P.P., Kumar, N.K.K. and Verghese, A.). Association for Advancement of Pest Management in Horticultural Ecosystems, Indian Institute of Horticultural Research, Bangalore, pp. 304-307

Haider, M.G., Jha, R.N. and Nath, R.P. 1988. Studies on nematodes of spices. Pathogenic effect of root-knot nematode (*Meloidogyne incognita*) and reniform nematodes (*Rotylenchulus reniformis*) alone and in combination on turmeric (*Curcuma longa* L.). *Indian J. Nematol.* 28: 52

Haider, M.G., Nath, R.P. and Srivastava, S.S. 2001. Evaluation of brinjal (*Solanum melongena* L.) germplasm for resistance against *Meloidogyne incognita* race-2. *Indian J. Nematol.* 31: 93-94

Hanna, A.I., Riad, F.W. and Twafik, A.E. 1999. Efficacy of antagonistic rhizobacteria on the control of root-knot nematode, *Meloidogyne incognita* in tomato plants. *Egyptian J. agric. Sci.* 77: 1467-1476

Haque, S.E., Abid, M., Sulatana, V., Ara, J. and Gharaffar, A. 1996. Use of organic amendments on the efficacy of biocontrol agents in the control of root rot and root-knot disease complex of okra. *Nematol. Medit.* 24: 13-16

Haque, S.E., Sultana, V., Abid, M., Ara, J. and Ghaffar, A. 1997. Use of *Calotropis procera* and microbial antagonists in the control of *Meloidogyne incognita* on mungbean. *Pakist. J. Phytopath.* 9: 108-110

Harish, M. and Gowda, D.N. 2001. Management of burrowing nematode, *Radopholus similis* (Cobb, 1893) Thorne, 1949 infesting banana. *Indian J. Nematol.* 31: 23-25

Haseeb, A. and Shukla, P.K. 2001. Screening of twenty cultivars of *Vigna radiata* against *Meloidogyne incognita*. Nat. Congr. Centenary Nematology India Appraisal Future Plans, 5-7 December, 2001. Nematological Society of India, Indian Council of Agricultural Research, National Academy of Agricultural Sciences, Indian Agricultural Research Institute, New Delhi. *Abstract*: 131

Haseeb, A., Butool, F. and Shukla, P. 1999. Effect of *Meloidogyne incognita* on the growth, physiology and oil yield of *Ocimum sanctum*. *Indian J. Nematol.* 29: 121-125

Hazarika, K. 1990. Pathogenicity and management of *Meloidogyne incognita* on brinjal. M.Sc. (Ag.) thesis, Assam Agricultural University, Jorhat, Assam, p. 110

Hazarika, K., Dutta, P.K. and Saikia, L. 1999. Yield losses in betelvines due to infestation of *Meloidogyne incognita*. *J. agric. Sci. Soc. E. India* 12: 268-270

Hazarika, K., Dutta, P.K., Saikia, L. and Deka, S.C. 2000. Biological control of root-knot nematode in betelvine using parasitic fungus, *Paecilomyces lilacinus*. *Crop Res.* 19: 338-342

Heald, C.M., Briton, B.D. and Davis, R.M. 1989. Influence of *Glomus intradices* and soil phosphorus on *Meloidogyne incognita* infecting *Cucumis melo*. *J. Nematol.* 21: 69-73

Hebsybai, Sheela, M.S. and Jiji, T. 1995. Nemic association and avoidable yield loss in turmeric, *Curcuma longa* L. *Pest Mgmt hort. Ecosystems* 1: 105-110

Herrera, C.R., Aballay, E. and Montealegre, A.J.R. 1999. Effect of lengthy solarization on the survival of the root-knot nematode (*Meloidogyne incognita*) in a monoculture of tomato (*Lycopersicon esculentum*). *Fitopatologia* 34: 63-68

Hooper, D.J. 1970. Extraction of nematodes from plant material. *Laboratory Methods for Work with Plant and Soil Nematodes* (ed. Southey, J.F.). Ministry of Agriculture, Fish and Food Technological Bull. 2. Her Majesty's Stationery Office, London, pp. 440

Hussain, S., Ahmad, R. and Khan, M.A. 1998. Growth responses of chilli cultivars to identify resistant sources against root-knot nematode *Meloidogyne incognita*. *Pakist. J. Phytopath.* 10: 101-104

Hussaini, S.S., Bharatha, K.S. and Rao, R.V.V.P. 2001. Soil solarization – comparison of LDPE gauges and periods for control of root-knot nematode and weeds in FCV tobacco nursery. *Curr. Nematol.* 12: 39-43

Ibrahim, I.K.A., Shahda, W.T. and Dawood, O.I. 1998. Reaction of egg plant and pepper cultivars to *Meloidogyne arenaria* and its biological control on egg plant. *Alexandria J. agric. Sci.* 43: 151-157

Jackson, M.L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi, p. 498

Jacob, A.J. and Haque, M.M. 1998. Effect of neem products on the suppression of root-knot nematode, *Meloidogyne incognita* on tomato. *Proc. Third int. Symp. Afro-Asian Soc. Nematologists, 16-19 April, 1998* (ed. Mehta, U.K.). Sugarcane Breeding Institute, Coimbatore, pp. 226-228

Jain, C. and Trivedi, P.C. 2000. Varietal screening of *Cicer arietinum* against root-knot nematode, *Meloidogyne incognita*. *Indian Phytopath.* 53: 99

Jain, R.K. and Dabur, K.R. 2000. Integrated approach for management of root-knot nematode infecting okra. Nat. Nematology Symp. Integrated Nematode Mgmt Sustainable Agric. Changing Agro-ecol. Econ. Scenario New Millennium, 23-24 November, 2000. Orissa University of Agriculture and Technology, Bhubaneswar. *Abstract*: 62

Jain, R.K. and Gupta, D.C. 1997a. Solarization as nursery bed treatment in the management of root-knot nematode infecting tomato. *Indian J. Nematol.* 27: 237-271

Jain, R.K. and Gupta, D.C. 1997b. Efficacy of neem (*Azadirachta indica*) cake as nursery bed treatment in the management of root-knot nematode, *Meloidogyne javanica* infecting tomato. *Indian J. Nematol.* 27: 249-251

Jain, R.K., Dabur, K.R. and Gupta, D.C. 1994. Assessment of avoidable losses in yield due to root-knot nematode (*Meloidogyne* spp.) in a few vegetable crops. *Indian J. Nematol.* 24: 181-184

Jain, R.K., Gupta, D.C. and Ram, S. 1997. Minimising yield losses due to root-knot nematode (*Meloidogyne incognita*) by using non-infected tomato seedlings. *Indian J. Nematol.* 27: 251-252

Jatala, P., Kaltenbach, R. and Bogangel, M. 1979. Biological control of *Meloidogyne incognita acrita* and *Globodera pallida* on potatoes. *J. Nematol.* 11: 303

Jatala, P.R., Kaltenabach, A.J., Devaux and Campos, R. 1980. Field application of *Paecilomyces lilacinus* for controlling *Meloidogyne incognita* on potatoes. *J. Nematol.* 12: 226-227

Jhala, A.J. and Patel, R.H. 2004. Management of root-knot nematode, *Meloidogyne incognita* through soil solarization and intercropping. Nat. Symp. Paradigms Nematological Res. Biodynamic Fmg, 17-19 November 2004. Nematological Society of India, University of Agricultural Sciences, GKVK, Bangalore. *Abstract*: 87

Jiji, T., Premila, K.S. and Sheela, M.S. 2000. Effect of nursery treatments for the management of root-knot nematode in brinjal. Nat. Nematology Symp. Integrated Nematode Mgmt Sustainable Agric. Changing Agro-ecol. Econ. Scenario New Millennium, 23-24 November, 2000. Orissa University of Agriculture and Technology, Bhubaneswar. *Abstract*: 82

Johnson, L.F. and Curl, E.A. 1972. *Methods for Research in the Ecology of Soil Borne Plant Pathogens*. Burgess Publishing Co., Minneapolis, 247 p.

Jonathan, E.I. and Rajendran, G. 2000a. Assessment of avoidable yield loss in banana due to root-knot nematode, *Meloidogyne incognita*. *Indian J. Nematol.* 30: 162-164

Jonathan, E.I. and Rajendran, G. 2000b. Biocontrol potential of the parasitic fungus *Paecilomyces lilacinus* against the root-knot nematode, *Meloidogyne incognita* in banana. *J. Biological Control* 14: 67-69

Jonathan, E.I., Arulmozhiyan, R., Muthusamy, S. and Mannuel, K.W. 2000. Field application of *Paecilomyces lilacinus* for the control of *Meloidogyne incognita* on betelvine, *Piper betle*. *Nematol. Medit.* 28: 131-133

Kalita, D.N., Sinha, A.K. and Phukan, P.N. 1999. Reaction of some cowpea cultivars to root-knot nematode, *Meloidogyne incognita*. *Indian J. Nematol.* 29: 96

Kamalakshiamma, P.L. 1986. Use of organic amendments for the control of root-knot nematode in brinjal. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, p. 67

Kamalwanshi, R.S., Khan, A. and Srivastava, A.S. 2004. Reaction of tomato germplasm against root-knot nematode, *Meloidogyne incognita*. *Indian J. Nematol.* 34: 94-95

Kamra, D.A. and Gaur, H.S. 1993. Efficiency of soil solarization and formaldehyde application alone and in combination on plant parasitic nematodes and growth of eggplant seedlings. Nat. Symp. Recent Approaches Integrated Nematode Mgmt agric. Crops, 6-7 August 1993. Haryana Agricultural University. *Abstract* : 80

Karuna, K., Krishnappa, K. and Reddy, B.M.R. 2001. Utilization of *Pasteuria penetrans* in the management of root-knot nematode on brinjal. Nat. Congr. Centenary Nematology India Appraisal Future Plans, 5-7 December 2001. Nematological Society of India, Indian Council of Agricultural Research, National Academy of Agricultural Sciences, Department of Science and Technology, Society of Plant Protection Sciences, Indian Agricultural Research Institute, New Delhi. *Abstract*: 142

KAU. 1993. Biennial Report of All India Co-ordinated Research Programme on Plant Parasitic Nematode with Integrated Approach for their Control, Kerala Agricultural University, Thrissur, p. 32

KAU. 2002. *Package of Practices Recommendations 'Crops'*. Twelfth edition. Directorate of Extension, Kerala Agricultural University, Thrissur, 278 p.

Kaul, V. and Bhat, O.K. 1995. Management of root-knot nematode, *Meloidogyne incognita* infesting tomato. Nat. Symp. Nematode Problems India–An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26 March 1995. Indian Agricultural Research Institute, New Delhi *Abstract*: 26

Kaur, D.J. and Mahajan, R. 1990. Reaction of some chilli cultivars to the root-knot nematode, *Meloidogyne incognita*. *Int. Nematol. Network Newsl.* 7: 23

Kerry, B.R.1980. Biocontrol: Fungal parasites of female cyst nematodes. *J. Nematol.* 12: 253-259

Keshari, N. and Pathak, K.N. 2000. Management of root-knot nematode, *Meloidogyne incognita* (Kofoid and White, 1949) Chitwood 1919, infecting red beet (*Beta vulgaris* var. *Crassa*) by organic amendments and carbofuran. *Pest Mgmt hort. Ecosystems* 6: 67-70

Khan, A.A. and Khan, M.W. 1991. Suitability of some cultivars of pepper as hosts for *M. javanica* and some races of *M. incognita*. *Nematol. Medit.* 19 (1) : 51-53

Khan, B., Khan, A.A. and Khan, M.R. 2002. Response of some cultivars of pepper, egg plant and tomato to races of root-knot nematodes, *M. incognita* and *M. javanica* . *Indian J. Nematol.* 32 (2) : 147-152

Khan, H.U., Ahmad, R., Ahmad, W., Khan, S.M. and Akhtar, A.S. 2000. Evaluation of chemical vs biological control treatments against root-knot nematode, *Meloidogyne incognita*, on tomato. *Pakist. J. Phytopath.*12: 118-120

Khan, M.L. 2000. Management of *Meloidogyne incognita* in tomato through *Pseudomonas fluorescens* and carbofuran. Nat. Nematology Symp. Integrated Nematode Mgmt Sustainable Agric. Changing Agro-ecol. Econ. Scenario New Millennium, 23-24 November, 2000. Orissa University of Agricultural Sciences and Technology, Bhubaneswar, Nematological Society of India, Indian Agricultural Research Institute, New Delhi. *Abstract:* 37

Khan, M.R. and Goswami, B.K. 2002. Evaluation of *Paecilomyces lilacinus* isolate 6 against *Meloidogyne incognita* infecting tomato. *Int. J. Nematol.* 12: 111-114

Khan, M.R. and Goswami, B.K. 2000. Effect of different doses of *Paecilomyces lilacinus* against *Meloidogyne incognita* eggs. *Indian J. Nematol.* 30: 86-110

Khan, M.R. and Tarannum, Z. 1999. Effects of field application of various microorganisms on *Meloidogyne incognita* on tomato. *Nematol. Medit.* 27: 233-238

Khan, T.A. and Saxena, S.K. 1995. Efficacy of *Paecilomyces lilacinus* to control the root-knot nematode species on tomato. Nat. Symp. Nematode Problems India–An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26 March 1995. Indian Agricultural Research Institute, New Delhi. *Abstract*: 114

Khanna, A.S. 2000. Biomanagement of *Meloidogyne incognita* (Kofoid and White) Chitwood by *Paecilomyces lilacinus* (Thom.) Samson on egg plant. *Pest Mgmt Economic. Zool.* 8: 133-136

Kumar, S.T. 2004. Host parasite relationship and management of important nematodes associated with chethikoduveli, *Plumbago rosea* L. Ph.D. thesis, Kerala Agricultural University, p. 192

Kuriyan, K.J. and Sheela, M.S. 1981. Integrated control of *M. incognita* on brinjal. *Indian J. Nematol.* 11: 129

Latha, T.K.S. and Sivakumar, C.V. 1998. Effect of culture filtrates of antagonistic organisms on cyst nematode, *Heterodera cajani* Koshy in blackgram. *J. Biological Control* 12: 143-145

Latha, T.K.S., Rajeswari, E. and Narasimhan, V. 2000. Management of root-rot disease complex through antagonists and chemicals. *Indian Phytopath.* 53: 216-218

Mahajan, R. 2002. Additional sources of resistance to the root-knot nematode (*Meloidogyne incognita*) in tomato. *Indian J. Nematol.* 32: 85

Mahajan, R. and Singh, J. 2001. Identification of sources of resistance to the root-knot nematodes, *Meloidogyne incognita* in tomato. *Indian J. Nematol.* 31: 170-171

Mahapatra, S.N. and Mohanty, K.C. 2000. Integrated management of root-knot nematode, *Meloidogyne incognita* through solarization and treated nursery of tomato. Nat. Nematology Symp. Integrated Nematode Mgmt Sustainable Agric. Changing Agro-ecol. Econ. Scenario New Millennium, 23-24 November 2000. Orissa University of Agriculture and Technology, Bhubaneswar. *Abstract*: 60

Maheswari, T.U. and Mani, A. 1988. Combined efficacy of *Pasteuria penetrans* and *Paecilomyces lilacinus* on the biocontrol of *Meloidogyne incognita* on tomato. *Int. Nematol. Network Newsl.* 5: 10-11

Maheswari, T.U., Mani, A. and Rao, P.K. 1987. Combined efficacy of the bacterial spore parasite, *Pasteuria penetrans* (Thorne 1940) and nematicides in the control of *Meloidogyne javanica* on tomato. *J. Biological Control* 1: 53-57

Makhnotra, A.K. and Khan, L. 1997. Assessment of yield losses in ginger due to *Meloidogyne incognita*. *Indian J. Nematol.* 27: 259-260

Malakeberhan, H., Brooke, R.C. and Webster, J.M. 1986. Relationship between physiological response of French beans of different age to *Meloidogyne incognita* and subsequent yield loss. *Pl. Path.* 35: 203-213

Mani, A. and Anandam, R.J. 1989. Evaluation of plant leaves, oil cakes and agro industrial wastes as substrates for mass multiplication of nematophagous fungus, *Paecilomyces lilacinus*. *J. Biological Control* 3: 56-58

Manzoor, S., Sinha, A.K. and Bora, B.C. 2002. Management of citrus nematode, *Tylenchulus semipenetrans* on khasi mandarin, by *Paecilomyces lilacinus*. *Indian J. Nematol.* 32: 153-155

Matsubara, H. and Feder, J. 1970. Other bacterial, mold and yeast protease. *Enzymes Vol. III. Hydrolysis*: *Peptide Bonds.* Third edition. (ed. Boyer, P.D.). Academic Press, New York, pp. 721-795

Melki, K., Tzorzakakis, E.A. and Gowen, S.R. 1995. The use of *Pasteuria penetrans* in the management of root-knot nematodes in protected crop. *Nematologica* 4: 321

Midha, R.L., Trivedi, P.C. and Yadav, B.D. 2001. *Paecilomyces* spp. as biocontrol agents against *Meloidogyne incognita* on coriander. Nat. Congr. Centenary Nematology India Appraisal Future Plans, 5-7 December 2001. Nematological Society of India, Indian Council of Agricultural Research, National Academy of Agricultural Sciences, Department of Science and Technology, Society of Plant Protection Sciences, Indian Agricultural Research Institute, New Delhi. *Abstract*: 146

Mikami, R.K., Yazava, K., Feukushima, T., Arai, S., Udagaura and Samson, R.A. 1989. Paecilotoxin production in clinical or terrestrial isolates of *Paecilomyces lilacinus* strains. *Mycopathologia* 108: 195-199

Mishra, S.D. and Goswami, B.K. 1993. Efficacy of neem and mustard oil seed cake and carbofuran against plant parasitic nematodes infesting chickpea. Nat. Symp. Recent Approaches Integrated Nematode Mgmt agric. Crops, 6-7 August 1993. Haryana Agricultural University, Hissar. *Abstract*: 11

Mohandas, C. and Ramakrishnan, S. 1997. Pathogenic effect of root-knot nematode, *Meloidogyne incognita* on African white yam, *Dioscorea rotundata*. *Indian J. Nematol.* 27: 233-236

Mohandas, C. and Ramakrishnan, S. 1998. Fluctuation in the population of root-knot nematode in Chinese potato tubers during storage. *J. Root Crops* 24: 55-57

Mohandas, C., Palaniswami, M.S. and Potty, V.P. 1988. Survey, identification and pathogenicity of nematodes in tuber crops. *Annual Report 1988*. Central Tuber Crops Research Institute, Sreekaryam, Thiruvananthapuram, pp. 74-75

Mohandas, C., Sreeja, P., Nageshwari, S. and Sheela, M.N. 1998. Identification of resistance in african yam against root-knot nematode. *Proc. nat. Symp. Rational Approaches Nematode Mgmt Sustainable Agric., 23-25 November 1998* (eds. Dhawan, S.C. and Kaushal, K.K.). Gujarat Agricultural University, B.A. College of Agriculture, Anand. Nematological Society of India, Indian Agricultural Research Institute, New Delhi, pp. 63-64

Mohanty, K.C. and Das, S.N. 1988. Resistance of some amaranthus varieties to root-knot nematode (*Meloidogyne incognita*). *Indian J. Nematol.* 18: 104-160

Mohanty, K.C., Mahapatra, S.N. and Patnaik, P.R. 1992. Integrated management of root-knot nematode, *Meloidogyne incognita* infecting ginger. *Indian J. Nematol.* 22: 70-71

Mohanty, K.C., Mahapatra, S.N. and Sahoo, N.K. 2000. Comparative efficacy of different oil cakes, biogas sludge and nematicide, carbofuran for the management of root-knot nematode, *Meloidogyne incognita* in papaya. Nat. Nematology Symp. Integrated Nematode Mgmt Sustainable Agric. Changing Agro-ecol. Econ. Scenario New Millennium, 23-24 November 2000. Orissa University of Agriculture and technology, Bhubaneswar, Nematological Society of India, Indian Agricultural Research Institute, New Delhi. *Abstract*: 55

Moity, T.H.A.E., Ali, E.M., Hamawi, M.H.E., Sharkawy, T.E. and Tilikkala, K. 1998. Effect of some biological agents on reproduction of *Meloidogyne incognita* on tomato plants. *Egyptian J. agric. Sci.* 76: 51-56

Mojumder, V., Dhawan, S.C., Pankaj and Singh, J. 2002. Compatibility of neem products and bioagents for the management of *Meloidogyne incognita* and *Rotylenchulus reniformis* infecting egg plant. *Indian J. Nematol.* 32: 197-198

Morgan-Jones, G. and Rodriguez-Kabana, R. 1984. Species of *Verticillium* and *Paecilomyces* as parasites of cyst and root-knot nematodes. *Phytopathol.* 74: 831

Morgan-Jones, G., White, J.F. and Rodreiquez-Kabana, R. 1983. Phytonematode Pathology. Ultra Structural Studies I. Parasitism of *Meloidogyne arenaria* eggs by *Verticillium chlamydosporium. Nematropica* 13: 245-260

Mukhtar, T., Ahmad, R. and Javed, N. 2002. Efficacy of *Pasteuria penetrans* and *Verticillium chlamydosporium* in the biological control of *Meloidogyne javanica. Pakist. J. Phytopath.* 14: 79-83

Nadpuri, K.S., Singh, S. and Mahajan, R. 1988. Punjab NR-7 a new root-knot nematode resistant tomato variety. *Indian J. Nematol.* 18: 104-160

Nagesh, M. 1996. Relationship between the population densities of root-knot nematode, *Meloidogyne incognita* (Kofoid and White, 1919), Chitwood, 1949 and growth of potato, *Solanum tuberosum* L. *Pest Mgmt hort. Ecosystems* 2: 9-14

Nagesh, M. and Reddy, P.P. 1995. Integrated management of *Meloidogyne incognita* on tube rose using ecofriendly antagonist, *Paecilomyces lilacinus* in combination with botanicals. Nat. Symp. Nematode Problems India: An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, March 24-26, 1995. Indian Agricultural Research Institute, New Delhi. *Abstract:* 33

Nagesh, M., Reddy, P.P. and Rama, N. 2001a. Influence of oil cakes in combination with inorganic fertilizers on growth and sporulation of *Paecilomyces lilacinus* and its antagonism on *Meloidogyne incognita* infecting tomato. *Nematol. Medit.* 29: 23-27

Nagesh, M., Hussaini, S.S. and Gopinatha, K.V. 2001b. Management of root-knot nematode, *Meloidogyne incognita* (Kofoid and White) Chitwood on chrysanthemum using formulations of *Paecilomyces lilacinus* in combination with neem cake. *Proc. Second nat. Symp. Integrated Pest Management hort. Crops, New Molecules, Biopesticides Environ." IPM hort. Crops: Emerging Trends New Millennium, 17-19 October 2001* (eds. Verghese, A and Reddy, P.P.). Association for Advancement of Pest Management in Horticultural Ecosystems, Bangalore, pp. 149-150

Nagesh, M., Reddy, P.P., Vijayakumar, M.V. and Nagaraju, B.M. 1998a. Management of *Meloidogyne incognita* on *Polianthes tuberosa* using parasitic fungus, *Paeciomyces lilacinus* in combination with oil cakes. *Proc. First nat. Symp. Pest Mgmt hort. Crops, 15-17 October 1997* (eds. Reddy, P.P., Kumar, N.K.K. and Verghese, A.). Association for Advancement of Pest Management in Horticultural Ecosystems, Indian Institute of Horticultural Research, Bangalore, pp. 321-323

Nagesh, M., Reddy, P.P. and Ramachander, N. 1998b. Integrated management of *Meloidogyne incognita* and *Fusarium oxysporum* f. sp. *gladioli* in gladiolus using antagonistic fungi and neem cake. *Proc. Third int. Symp. Afro-Asian Soc. Nematologists, 16-19 April 1998* (ed. Mehta, U.K.). Sugarcane Breeding Institute, Coimbatore, pp. 263-266

Naidu, P.H., Moses, G.J. and Sitaramaiah, K. 2000. Chemical composition of groundnut seed and their relationship to *Tylenchorhynchus brevilineatus* infestation (*Kalahasti malady*). *Indian J. Nematol.* 30: 183-185

Nakat, R.V., Acharya, A., Jonathan, E.I., Hazarika, K., Jha, S., Singh, U.S., Washnikar, A.R., Rao, D.V.S. and Sitaramaiah, K. 1995. Evaluation of *Paecilomyces lilacinus* for the control of root-knot nematode *Meloidogyne incognita* on betel vine. Nat. Symp. Nematode Problems India: An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26 March 1995. Indian Agricultural Research Institute, New Delhi. *Abstract:* 44

Nakat, R.V., Acharya, A., Jonathan, E.I., Hazarika, K., Jha, S., Singh, U.S., Washnikar, A.R., Rao, D.V.S. and Sitaramaiah, K. 1998. Evaluation of *Paecilomyces lilacinus* for the management of root-knot nematode (*Meloidogyne incognita*) on betel vine. *Proc. First nat. Symp. Pest Mgmt hort. Crops, 15-17 October 1997* (eds. Reddy, P. P., Kumar, N.K.K. and Varghese, A.). Association for Advancement of Pest Management in Horticultural Ecosystems, Indian Institute of Horticultural Research, Bangalore, pp. 308-311

Nalinakumari, T., Sheela, M.S., Hebsybai and Kuriyan, K.J. 1995. Comparative effect of root-knot and reniform nematode on growth and yield of betelvine. *Indian J. Nematol.* 25: 14-15

Nayak, D.K. 1995. Evaluation of tomato and brinjal varieties against root-knot nematode, *Meloidogyne incognita. Indian J. Nematol.* 25: 107-125

Neipp, P.W. and Becker, J.O. 1999. Evaluation of biocontrol activity of rhizobacteria from *Beta vulgaris* against *Heterodera schachtii*. *J. Nematol.* 31: 54-61

Nema, A.G. 2001. Control of nematodes in betelvine in standing gardens infested with root-knot nematodes. *Adv. Pl. Sci.* 14: 589-590

Niknam, G.R. and Dhawan, S.C. 2002. *In vitro* study on the efficacy of *Bacillus subtilis* Bst cell concentrations and cell free filtrates on hatching and mobility of *Rotylenchulus reniformis*. *Indian J. Nematol.* 32: 9-15

Nisha, M.S. and Sheela, M.S. 2003. Preliminary study of the effect of bioagents and organic amendments for the management of root-knot nematode associated with kacholam, *Kaempferia galanga* Linn. *Pest Mgmt hort. Ecosystems* 9: 165-168

Oka, Y., Chet, I. and Spiegel, Y. 1993. Control of the root knot nematode *Meloidogyne javanica* by *Bacillus cereus*. *Biocontrol Sci. Technol.* 3 : 115-126

Orion, D., Bronner, R. 1973. The localization of starch, amylase and invertase in *Meloidogyne javanica* galls. *Nematologica* 19: 401-402

Owino, P.O. 2003. Integrated management of root-knot nematodes using agrochemicals, organic matter and the antagonistic fungus, *Paecilomyces lilacinus* in natural field soil. *Nematol. Medit.* 31: 121-123

Pandey, G. and Singh, K.P. 1990. Effect of organic amendments on soil microflora and nematode fauna with special reference to *Meloidogyne incognita* in chickpea. *New Agriculturist* 1: 65-70

Pandey, R. 1995. Performance of oil seed cake, pesticides and dry leaf matter on the reproduction potential of *Meloidogyne incognita* and yield of Japanese mint HY-77. Nat. Symp. Nematode Problems India–An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26 March 1995. Indian Agricultural Research Institute, New Delhi. *Abstract*: 36

Pandey, R. and Trivedi, P.C. 1990. Response of chilli cultivars to *Meloidogyne incognita* and its effect on morphometrics of female. *Nematol. Medit.* 18: 219-220

Pant, H. and Pandey, R. 2001. Efficacy of biocontrol agents for the management of root-knot nematode on chickpea. *Ann. Pl. Protection Sci.* 9: 157-159

Pant, H. and Pandey, G. 2002. Use of *Trichoderma harzianum* and neem cake alone and in combination on *Meloidogyne incognita* galls in chickpea. *Ann. Pl. Protection Sci.* 10: 175

Parihar, A., Siddiqui, A.V. and Seth, P. 1995. Some bio-chemical changes associated with maize infected with corn cyst nematode (*Heterodera zeae*). Nat. Symp. Nematode Problems India–An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26 March 1995. Indian Agricultural Research Institute, New Delhi. *Abstract*: 69

Patel, B.K. and Patel, H.R. 1998. Effect of soil solarization, rabbing, nematicides and green manuring on growth and development of bidi tobacco seedlings, root-knot disease, weeds and phytonematodes in nursery. *Indian J. Nematol.* 28: 15-21

Patel, B.N., Patel, S.K., Patel, A.D., Patel, H.V. and Patel, D.J. 2000. Economic loss caused by root-knot disease in papaya nursery. Nat. Nematology Symp. Integrated Nematode Mgmt Sustainable Agric. Changing Agro-ecol. Econ. Scenario New Millennium, 23-24 November 2000. Orissa University of Agriculture and technology, Bhubaneswar, Nematological Society of India, Indian Agricultural Research Institute, New Delhi. *Abstract*: 38

Patel, D.J., Makadia, B.M. and Shah, H.M. 1981. Occurrence of root-knot nematode on turmeric (*Curcuma longa*) and its chemical control. *Indian J. Nematol.* 11: 125

Patel, D.J., Patel, H.B. and Patel, S.K. 1993. Estimation of avodable yield losses in green gram and cowpea due to root-knot nematode in field. Nat. Symp. Recent Approaches Integrated Nematode Mgmt Agric. Crops, 6-7 August 1993. Haryana Agricultural University, Hissar. *Abstract*: 18

Patel, D.S. and Thakar, N.A. 1988. Pathogenicity of the reniform nematode, *Rotylenchulus reniformis* on mung bean variety Gujarat-I. *Indian J. Nematol.* 18: 332-333

Patel, H.R., Makwana, M.G. and Patel, B.N. 1995. Effect of soil solarization using clear LDPE plastic of varying thickness for different tarping durations against nematodes and weeds in bidi tobacco nursery. Nat. Symp. Nematode Problems India : An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26 March 1995. Indian Agricultural Research Institute, New Delhi. *Abstract*: 46

Patel, H.R., Patel, B.A., Vyas, R.V. and Patel, D.J. 1998. Organic amendments in management of root-knot nematodes in bottle gourd. *Proc. nat. Symp. Rational Approaches Nematode Mgmt Sustainable Agric., 23-25 November 1998* (eds. Dhawan, S.C. and Kaushal, K.K.) Nematological Society of India, Indian Agricultural Research Institute, New Delhi, pp. 7-9

Patel, N.B., Vyas, R.V. and Patel, D.J. 1998. Efficacy of *Paecilomyces lilacinus* for the management of *Meloidogyne javanica* pf-2 on groundnut. *Proc. nat. Symp. Rational Approaches Nematode Mgmt Sustainable Agric., 23-25 November 1998* (eds. Dhawan, S.C. and Kaushal, K.K.). Gujarat Agricultural University, Anand, pp. 23-24

Pathak, K.N. and Keshari, N. 2000. Effect of inoculum levels of *Meloidogyne incognita* (Kofoid and White, 1949) Chitwood, 1919, on seed germination, seedling emergence and plant growth of red beet (*Beta vulgaris* var. Crassa). *Pest Mgmt hort. Ecosystems* 6: 118-123

Patnaik, P.R. and Das, S.N. 1986. Pathogenicity of *Meloidogyne incognita* on edible coleus. *Indian J. Nematol.* 16: 271-272

Patnaik, P.R., Mohanty, K.C., Mahapatra, S.N. and Sahoo, S. 2004. Evaluation of chilli varieties against root-knot nematode, *Meloidogyne incognita.* Nat. Symp. Paradigms Nematological Res. Biodynamic Fmg, 17-19 November 2004. Nematological Society of India, University of Agricultural Sciences, GKVK, Bangalore. *Abstract*: 10

Paulson, R.E. and Webster, J.M. 1972. Ultrastructure of the hypersensitive reaction in roots of tomato, *Lycopersicon esculentum* L. to infection by the root-knot nematode, *Meloidogyne incognita. Physiol. Pl. Path.* 2: 227-234

Pillai, K.S. 1976. Nematicidal control of root-knot nematode on edible coleus. *J. Root Crops* 2: 60-63

Prasad, P.R.K. and Reddy, D.D.R. 1984. Pathogenicity and analysis of crop loss in patchouli due to *Meloidogyne incognita. J. Nematol.* 14: 36-38

Prasad, R.S. 1981. Growth responses of greengram, *Vigna radiata* L. Wilezek against root-knot nematode, *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949. M.Sc. (Ag.) thesis, Department of Entomology, Rajendra Agricultural University, Bihar, p. 80

Praveen, G., Sultan, M., Arif, M. and Alam, M.M. 1995. Reaction of pea cultivars / accessions against root-knot nematode, *Meloidogyne incognita. Curr. Nematol.* 6: 103-104

Praveen, H.M. and Gowda, D.N. 2004. Screening of Gherkin (*Cucumis anguria* L.) cultivars against root-knot nematode, *Meloidogyne incognita. Indian J. Nematol.* 34: 109-111

Praveen, S., Haque, S.E. and Ghaffer, A. 1998. Efficacy of *Pseudomonas aeruginosa* and *Paecilomyces lilacinus* in the control of root-knot disease complex in some vegetables. *Nematol. Medit.* 26: 209-212

Racke, J. and Sikora, R.A. 1992. Influence of the plant health promoting rhizobacteria *Agrobacterium radiobacter* and *Bacillus sphaeriacus* on *Globodera pallida* root infection of potato and subsequent plant growth. *J. Phytopathol.* 32 : 198-208

Rajani, T.S. 1998. Bio-ecology and management of root-knot nematode, *Meloidogyne incognita* (Kofoid and White) Chitwood in kacholam, *Kaempferia galanga* Linn. M Sc (Ag) thesis. Kerala Agricultural University, Thrissur, 67 p.

Rajani, T.S., Sheela, M.S. and Sivaprasad, P. 1998. Management of nematodes associated with kacholam, *Kaempferia galanga* L. *Proc. First nat. Symp. Pest Mgmt hort. Crops, 15-17 October 1997* (eds. Reddy, P.P., Kumar, N.K.K. and Verghese, A.). Association for Advancement of Pest Management in Horticultural Ecosystems, Indian Institute of Horticultural Research, Bangalore, pp. 326-327

Ramakrishnan, S. and Rajendran, G. 1998. Assessment of yield loss due to *Meloidogyne incognita* in papaya under field conditions. *Nematol. Medit.* 26: 229-230

Ramana, K.V. and Sarma, Y.R. 1993. Efficacy of *Paecilomyces lilacinus* in suppressing nematode infestations in black pepper (*Piper nigrum* L.). Nat. Symposium Recent Approaches Integrated Nematode Mgmt agric. Crops, August 6-7, 1993. Haryana agricultural University. *Abstract* : 7

Rao, D.V.S., Sitaramaiah, Sitaramaiah, K. and Maiti, S. 1995. Integrated management of plant parasitic nematodes in betelvine gardens. Nat. Symp. Nematode Problems India–An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26 March 1995. Indian Agricultural Research Institute, New Delhi. *Abstract*: 45

Rao, M.S. and Gowen, S.R. 1998. Biomanagement of *Meloidogyne incognita* on tomato by integrating *Glomus deserticola* and *Pasteuria penetrans*. *Z.-fur-pflan. Kheiten pflan.* 105: 49-52

Rao, M.S. and Naik, D. 2003. Effect of *Trichoderma harzianum* and *Paecilomyces lilacinus* on *Meloidogyne incognita* on papaya (*Carica papaya* L.) nursery seedlings. *Pest Mgmt hort. Ecosystems* 9: 155-160

Rao, M.S. and Reddy, P.P. 1992. Prospects of management of root-knot nematode on tomato through the integration of biocontrol agents and botanicals. *Indian Phytopath.* 46: 337

Rao, M.S. and Reddy, P.P. 1993. Interactive effect of *Verticillium chlamydosporium* and castor cake on the control of root-knot nematode on egg plant. *Soil Organisms and Sustainability* (eds. Rajagopal, D. and Kale, R.D. and Bano, K.). Indian Society of Soil Biology and Ecology, University of Agricultural Sciences, Bangalore, pp. 119-123

Rao, M.S. and Reddy, P.P. 2001. Control of *Meloidogyne incognita* on aubergines using *Glomus mosseae* integrated with *Paecilomyces lilacinus* and neem cake. *Nematol. Medit.* 29: 153-157

Rao, M.S., Mohandas, S. and Reddy, P.P. 1993. Integrated management of root-knot nematode on egg plant in nursery beds with the combination of *Glomus moseae* and neem leaf. *Nat. Symp. Recent Approaches Integrated Nematode Mgmt agric. Crops, 6-7 August 1993*. C.C.S., Haryana Agricultural University, Hissar, p. 76

Rao, M.S., Reddy, P.P. and Nagesh, M. 1997a. Effective use of neem cake extract for the management of root-knot nematodes infecting okra (*Abelmoschus esculentus*). *Pest Mgmt hort. Ecosystems* 3: 95-99

Rao, M.S., Reddy, P.P. and Nagesh, M. 1997b. Management of root-knot nematode, *Meloidogyne incognita* by integration of *Trichoderma harzianum* with neem cake. *Z.-fur-pflan. Kheiten pflan.* 104: 423-425

Rao, M.S., Reddy, P.P. and Nagesh, M. 1998a. Evaluation of *Paecilomyces lilacinus* cultivated on neem cake extract for the management of root-knot nematode on egg plant. *Pest Mgmt hort. Ecosystems* 4: 116-119

Rao, M.S., Reddy, P.P. and Nagesh, M. 1998b. Integrated management of *Meloidogyne incognita* on tomato using oil cakes and a bioagents, *Verticillium chlamydosporium. Proc. First nat. Symp. Pest Mgmt hort. Crops, 15-17 October 1997* (eds. Reddy, P.P., Kumar, N.K.K. and Verghese, A.). Association for Advancement of Pest Management in Horticultural Ecosystems, Indian Institute of Horticultural Research, Bangalore, pp. 345-348

Rao, M.S., Reddy, P.P. and Nagesh, M. 1998c. Integrated management of *Meloidogyne* on tomato using *Verticillium chlamydosporium* and *Pasteuria penetrans. Pest Mgmt hort. Ecosystems* 4: 32-35

Rao, MS., Reddy, P.P. and Mohandas, S. 1995. Studies on development of a bio-rational management strategy against root-knot nematode attacking tomato. Nat. Symp. Nematode Problems India–An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26 March 1995. Indian Agricultural Research Institute, New Delhi. *Abstract*: 33

Rao, V.K., Rajeev, K.G., Krishnappa, K. and Reddy, B.M.R. 1995. Use of bioagents and biocomponents in the integrated approach to manage *Meloidogyne incognita* on chickpea and tomato. Nat. Symp. Nematode Problems India–An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26 March 1995. Indian Agricultural Research Institute, New Delhi. *Abstract*: 59

Rashid, A., Farooqi, T.N.A., Misra, S.R. and Singh, K. 1985. Changes in sugars in sugarbeet roots induced by root-knot nematodes, *Meloidogyne incognita*. *Indian J. Ent.* 47: 292-294

Ravichandra, N.G., Krishnappa, K. and Setty, K.G.H. 1988. Evaluation of brinjal (*Solanum melongena* L.) germplasm for resistance against *Meloidogyne javanica* and race-1, race-2 and race-3 of *Meloidogyne incognita*. *Indian J. Nematol.* 18: 165-175

Reddy, P.P. 1986. Analysis of crop loss in certain vegetables due to *Meloidogyne incognita*. *Int. Nematol. Network Newsl.* 3: 3-5

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

Reddy, P.P. and Khan, R.M. 1989. Evaluation of biocontrol agent *Paecilomyces lilacinus* and carbofuran for the management of *Rotylenchulus reniformis* infecting brinjal. *Pakist. J. Nematol.* 7: 55-59

Reddy, P.P. and Khan, R.M. 1991a. Integrated management of citrus nematodes, *Tylenchulus semipenetrans* using oil cakes and *Paecilomyces lilacinus*. *Afro-Asian J. Nematol.* 1: 221-222

Reddy, P.P. and Khan, R.M. 1991b. Integrated management of root-knot nematodes infecting okra. *Curr. Nematol.* 2: 115-116

Reddy, P.P., Khan, R.M. and Rao, M.S. 1991. Integrated management of the citrus nematode, *Tylenchulus semipenetrans* using oil cakes and *Paecilomyces lilacinus*. *Afro-Asian J. Nematol.* 1: 221-222

Reddy, P.P., Khan, R.M. and Rao, M.S. 1996. Integrated management of the citrus nematode, *Tylenchulus semipenetrans* using pesticides and parasitic fungus, *Paecilomyces lilacinus*. *Pest Mgmt hort. Ecosystems* 2: 61-63

Reddy, P.P., Nagesh, M. and Devappa, V. 1997. Effect of integration of *Pasteurea penetrans, Paecilomyces lilacinus* and neem cake for the management of root-knot nematode infecting tomato. *Pest Mgmt hort. Ecosystems* 3: 100-104

Reddy, P.P., Rangaswamy, S.D. and Nagesh, M. 2000. Integrated management of *Meloidogyne incognita* (Kofoid and White) Chitwood on tomato in nursery and main field. *Pest Mgmt hort. Ecosystems* 6: 47-49

Reddy, P.P., Rao, M.S. and Nagesh, M. 1995. An ecofriendly approach for the management of the citrus nematode, *Tylenchulus semipenetrans* using oil cakes and bioagent. Nat. Symp. Nematode Problems India–An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26 March 1995. Indian Agricultural Research Institute, New Delhi. *Abstract*: 34

Reddy, P.P., Rao, M.S. and Nagesh, M. 1999. Eco-friendly management of *Meloidogyne incognita* on tomato by integration of *Verticillium chlamydosporium* with neem and calotropis leaves. *Z.-fur-pflan. kheiten-pflan.* 106: 58-60

Reddy, S.G., Rao, K.V., Sitaramaiah, K. and Chalam, T.V. 2001. Soil solarization for control of soil borne pathogen complex due to *Meloidogyne incognita* and *Pythium aphanidermatum*. *Indian J. Nematol.* 31: 136-138

Roy, T.K. 1979. Histochemical studies of hydrolytic enzymes in *Meloidogyne incognita* (Nematoda: Tylenchidae) and infected host *Lycopersicum esculentum* and their role in host parasite relationship. *Indian J. Exp. Biol.* 17: 1357-1362

Saikia, D.K. and Phukan, P.N. 1986. Estimation of loss in jute due to root-knot nematode, *Meloidogyne incognita*. *Indian J. Nematol.* 16: 108-109

Saikia, M.K. and Roy, A.K. 1994. Efficacy of *Paecilomyces lilacinus* on the reduction of attack of *Meloidogyne incognita* on okra. *Indian J. Nematol.* 24: 163-167

Saikia, M.K. and Das, D. 2001. Integration of carbofuran with *Paecilomyces lilacinus* for the control of root-knot nematode, *Meloidogyne incognita* on brinjal. *Ann. Biol.* 17: 79-82

Sankaranarayanan, C., Hussaini, S.S., Kumar, P.S. and Rangeshwaran, R. 2001. Evaluation of substrates for the multiplication of *Verticillium chlamydosporium* Goddarad and its biocontrol efficacy against *Heterodera cajani* Koshy on pigeonpea. *Ann. Pl. Prot. Sci.* 9: 73-76

Sankaranarayanan, C., Hussaini, S.S., Kumar, P.S. and Rangeshwaran, R. 1998. Biocontrol of root-knot nematode (*Meloidogyne incognita*) on sunflower with talc based nematophagous fungi. *Int. J. trop. Pl. Dis.* 16: 253-260

Sankaranarayanan, C., Hussaini, S.S., Sreeramakumar, P. and Rangeshwaran, R. 2000. Granular application of antagonistic fungi for the biological control of *Meloidogyne incognita* on tomato. *Indian J. Nematol.* 30: 157-161

Sathyarajan, P.K., Das, N.M. and Nair, M.R.G.K. 1966. Root-knot nematode as a pest of *Coleus parviflorus* in Kerala. *Agric. Res. J. Kerala* 4: 144-145

Seenivasan, N., Parameswaran, S., Sridar, P.R., Gopalakrishnan, C. and Gnanamurthy, P. 2001. Application of bioagents and neem cake as soil application for the management of root-knot nematode in turmeric. Nat. Congr. Centenary Nematology India Appraisal Future Plans, 5-7 December 2001. Nematological Society of India, Indian Council of Agricultural Research, National Academy of Agricultural Sciences, Department of Science and Technology, Society of Plant Protection Sciences, Indian Agricultural Research Institute. *Abstract*: 164

Sekhar, N.S. and Gill, J.S. 1991. Efficacy of *Pasteuria penetrans* alone and in combination with carbofuran in controlling *Meloidogyne incognita*. *Indian J. Nematol.* 21: 61-65

Shafique, M., Ahmad, R., Khan, H.U. and Rehman, A. 2001. Comparative efficacy of different organic amendments in the control of root-knot nematode (*Meloidogyne incognita*) (Treub) Chitwood in mungbean. *Pakist. J. Nematol.* 13: 12-14

Shahzad, S.A., Ahmad, R. and Inam-Ul-Haq, M. 1999. Screening of tomato cultivars against root-knot nematode (*Meloidogyne incognita*). *Pakist. J. Phytopath.* 11: 74-76

Sharma, A. and Trivedi, P.C. 1989. Influence of inoculum levels of fungus, *Paecilomyces lilacinus* (Thom.) Samson on the biocontrol of root-knot nematode, *Meloidogyne incognita* (Chitwood). *Int. Nematol. Network Newsl.* 6: 27-29

Sharma, D.D., Chandrasekhar, D.S., Gunasekhar, V., Rekha, M., Sarkar, A. 2001. Comparative efficacy of different control measures against root-knot nematode disease of mulberry. *Indian J. Seric.* 40: 151-157

Sharma, G.L. and Samar, R. 1995. Effect of varied population of *Meloidogyne incognita* and *Pasteuria penetrans* in the root-knot disease development on tomato. Nat. Symp. Nematode Problems India—An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26 March 1995. Indian Agricultural Research Institute, New Delhi. *Abstract*: 17

Sharma, H.K., Pankaj, Sivanand, D.C., Pachauri and Singh, G. 2004. Reaction of tomato (*Lycopersicon esculentum*) varieties / lines to *Meloidogyne incognita* Race-1. *Indian J. Nematol.* 34: 93

Sharma, S.K., Sinha, A.K. and Phukan, P.N. 1994. Reaction of chilli cultivars to *M. incognita*. *Indian J. Nematol.* 24 : 237-238

Sharma, W. and Trivedi, P.C. 1996. Biochemical evaluation of various metabolites as influenced by root-knot nematode in *Abelmoschus esculentus*. *Indian J. Nematol.* 26: 152-157

Sharma, W. and Trivedi, P.C. 1997. Concomitant effect of *Paecilomyces lilacinus* and vesicular arbuscular fungi on root-knot nematode infesting okra. *Ann. Pl. Prot. Sci.* 5: 70-74

Sheela, M.S. 1991. Control of root-knot nematode, *Meloidogyne incognita* (Kofoid and White) Chitwood infesting black pepper (*Piper nigrum*) by bacterial pathogens. Ph.D. thesis, Kerala Agricultural University, p. 146

Sheela, M.S. and Jiji, T. 1999. Evaluation of different nematode management techniques for vegetable production. *Proc. nat. Sem. Participating Approaches hort. Dev. HORTINDIA'99, 8-9 January 1999* (ed. Kesavan, P.K). Kerala Horticulture Development Programme, Thiruvananthapuram, pp. 52-54

Sheela, M.S. and Nisha, M.S. 2004. Impact of biological control agents for the management of root-knot nematode in brinjal. Nat. Symp. Paradigms Nematological Res. Biodynamic Fmg, 17-19, November 2004. Nematological Society of India, University of Agricultural Sciences, Bangalore. *Abstract*: 63

Sheela, M.S. and Venkitesan, T.S. 1992. Bacterial pathogens associated with root-knot nematode in Kerala – their occurrence and status. *Proc. Fourth Kerala Sci. Congr., February 27-29, 1992* (ed. Nair, C.G.R.), Thrissur, pp. 231-233

Sheela, M.S., Hebsybai, Jiji, T. and Kuriyan, K.J. 1995. Nematodes associated with ginger rhizosphere and their management in Kerala. *Pest Mgmt hort. Ecosystems* 1: 43-48

Sheela, M.S., Nisha, M.S. and Mohandas, C. 2004. Eco-friendly management of nematodes associated with Chinese potato (Coleus), *Solenostemon rotundifolius* (Poir) Morton. Nat. Symp. Paradigms Nematological Res. Biodynamic Fmg, 17-19, November 2004. Nematological Society of India and University of Agricultural Sciences, Bangalore. *Abstract*: 90

Sheela, M.S., Venkitesan, T.S. and Mohandas, N. 1993. Status of *Bacillus* spp. as biocontrol agents of root-knot nematode (*Meloidogyne incognita*) infesting black pepper (*Piper nigrum* L.). *J. Plantn. Crops* 21: 218-222

Shelke, S.S., Mhase, N.L., Ghorpade, S.A. and Warade, S.D. 1995. Screening of some tomato varieties and promising germplasms against root-knot nematode, *Meloidogyne incognita* race-2. *Curr. Nematol.* 6: 75-77

Siddiqui, I.A. and Haque, S.E. 2000. Effect of *Verticillium chlamydosporium* and *Pseudomonas aeruginosa* in the control of *Meloidogyne javanica* on tomato. *Nematol. Medit.* 28: 193-196

Siddiqui, M.A., Haque, S.E. and Ghaffar, A. 1999. Use of *Pseudomonas aeruginosa* and fungal antagonists in the control of root-knot rot disease complex on mung bean and mash bean. *Pakist. J. Nematol.* 17: 155-167

Siddiqui, Z.A. and Mahmood, I. 1995. Some observation on the management of wilt disease complex of pigeon pea by treatment with vesicular arbuscular fungus and biocontrol agents for nematodes. *Biores. Tech.* 57: 227-230

Simpson, J.E., Adair, C.R., Kohler, G.D., Dawson, E.N., Debald, H.A., Kester, E.B. and Klick, J.T. 1965. Quality evaluation of foreign and domestic rices. *Tech. Bull. No.* 331 Series, U.S. Dept. Agric., Washington D.C., p. 250

Simte, H.C. and Dasgupta, D.R. 1987. Sequential changes in proteins of soybean inoculated with root-knot nematode, *Meloidogyne incognita*. *Indian J. Nematol.* 17: 241-246

Singh, D.B., Reddy, P.P. and Joshi, S. 1984. Histological, histopathological, histochemical investigations on root-knot nematode resistant and susceptible lines of cowpea. *Nematol. Medit.* 12: 213-219

Singh, I., Sharma, J. and Sharma, R. 1978. Biochemical alterations induced by *Meloidogyne incognita* in brinjal. *Indian J. Nematol.* 8: 122-126

Singh, R. 1977. Studies on effect of root-knot nematodes, *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949 alone and in combination with some *Fusarium* spp. on seedling emergence and growth of cauliflower, brinjal and tomato. M.Sc. (Ag.) thesis, Rajendra Agricultural University, Bihar, p. 91

Singh, R.V. and Vinodkumar. 1995. Effect of carbofuran and neem cake on *Meloidogyne incognita* infecting Japanese mint. Nat. Symp. Nematode Problems India–An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, 24-26 March 1995. Indian Agricultural Research Institute, New Delhi. *Abstract*: 37

Singh, S. and Goswami, B.K. 2001. Studies on the management of disease complex caused by root-knot nematode, *Meloidogyne incognita* and wilt fungus, *Fusarium oxysporum* on cowpea by neem cake and carbofuran. *Indian J. Nematol.* 31:122-125

Singh, S.P., Khan, A.M. and Saxena, S.K. 1980. Effect of nematicides and oil cakes separately in mixture on plant parasitic nematodes. *Geobios* 7: 111-113

Sirohi, A. and Dasgupta. 1993. Mechanisms of resistance in cowpea to the root-knot nematode, *Meloidogyne incognita* race-1-early induction of phenyl alanine ammonia lyase and chlorogenic acid. *Indian J. Nematol.* 23: 31-41

Sirohi, A., Chawla, G. and Dhawan, S.C. 2000. *Bacillus* and *Pseudomons* culture filtrates of promise for nematode management. Nat. Nematology Symp. Integrated Nematode Mgmt Sustainable Agric. Changing Agro-ecol. Econ. Scenario New Millennium, 23-24 November 2000. Orissa University of Agriculture and Technology, Bhubaneswar. *Abstract*: 72

Sivakumar, M. 1998. Non-chemical management of *Meloidogyne hapla* Chitwood on carrot (*Dacus carotae*). *Proc. Third int. Symp. Afro-Asian Soc. Nematologists, 16-19 April 1998* (ed. Mehta, U.K.), Sugarcane Breeding Institute, Coimbatore, pp. 209-212

Sosamma, P. 1988. Crop loss caused by root-knot nematode, *Meloidogyne incognita* (Kofoid and White) Chitwood infesting *Coleus parviflorus* and its control. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, p. 69

Sosamma, V.K. and Koshy, P.K. 1995. Effect of *Pasteuria penetrans* and *Paecilomyces lilacinus* on population buildup of root-knot nematode, *Meloidogyne incognita* on black pepper. Nat. Symp. Nematode Problems India : An Appraisal Nematode Mgmt Ecofriendly Approaches Biocomponents, March 24-26, 1995. Indian Agricultural Research Institute, New Delhi. *Abstract*: 47

Sosamma, V.K. and Koshy, P.K. 1997. Biological control of *Meloidogyne incognita* on black pepper by *Pasteuria penetrans* and *Paecilomyces lilacinus*. *J. Plantation Crops* 25: 72-76

Sosamma, V.K., Geetha, S.M. and Koshy, P.K. 1990. Effect of the fungus *Paecilomyces lilacinus* on the burrowing nematode, *Radopholus similis* infesting betelvine. *Sem. Bioagents Nematode Mgmt,* July 13, 1990. Indian Agricultural Research Institute, New Delhi, p. 52

*Spiegal, Y. and Cohn, E. 1985. Chitin is present in gelatinous matrix of *Meloidogyne*. *Revue de Nematol.* 8: 184-186

*Stephan, Z.A., El-Behaldi, A.H., Al-Zahroo, H.H., Antoon, B.G. and Georgees, M.S. 1996. Control of root-knot wilt disease complex on tomato plants. *Dirasat-Series-B-Pure appl. Sci.* 23: 13-16

Subhadra, B., Krishnappa, K. and Reddy, B.M.R. 1998. Integrated management of nematode complex on banana using physical, cultural and chemical methods. *Mysore J. agric. Sci.* 32: 148-153

Subramaniyan, S., Rajendran, G. and Vadivelu, S. 1990. Estimation of loss in tomato due to *Meloidogyne incognita* and *Rotylenchulus reniformis*. *Indian J. Nematol.* 28: 239

Sudha, S. and Sundararaju, P. 2001. Integrated approach for the management of burrowing nematode, *Radopholus similis* in arecanut based cropping system. *Indian J. Nematol.* 31: 26-33

Sudha, S., Sundararaju and Iyer, R. 2000. Effect of *Paecilomyces lilacinus* for the control of burrowing nematode *Radopholus similis* on arecanut seedling. *Indian J. Nematol.* 30: 86-110

Sujatha, B., Lakshman, P.L. and Kumari, N.S. 2000. Evaluation of rhizobacteria, *Pseudomonas fluorescens* against the cyst nematode, *Heterodera cajani*. Nat. Nematology Symp. Integrated Nematode Mgmt Sustainable Agric. Changing Agro-ecol. Econ. Scenario New Millennium, 23-24 November 2000. Orissa University of Agricultural Sciences and Technology, Bhubaneswar, Nematological Society of India, Indian Agricultural Research Institute, New Delhi. *Abstract:* 27

Sundarababu, R. and Vadivelu, S. 1990. Onion varietal response to three species of *Meloidogyne*. *Indian J. Nematol.* 20: 76-78

Sundaram, R. 2001. Reaction of chilly genotypes to *Meloidogyne incognita*. Nat. Congr. Centenary Nematology India Appraisal Future Plans, 5-7 December 2001. Nematological Society of India, Indian Council of Agricultural Research, National Academy of Agricultural Sciences, Department of Science and Technology, Society of Plant Protection Sciences, Indian Agricultural Research Institute. *Abstract*: 133

Sundararaju, P. and Sudha, S. 1993. Nematode management in arecanut and arecanut based farming system. Nat. Symp. Recent Approaches Integrated Nematode Mgmt agric. Crops, *6-7 August 1993*. Haryana Agricultural University, Hissar. Nematological Society of India, Indian Agricultural Research Institute, New Delhi. *Abstract*: 78

Tayal, M.S. and Agarwal, M.L. 1982. Biochemical alterations in galls induced by *Meloidogyne incognita* : some hydrolyzing enzymes and related chemical metabolites. *Indian J. Nematol.* 12: 379-382

Thakur, S.G. and Darekar, K.S. 1995. Effect of some non-edible oil seed cakes against root-knot nematode, *Meloidogyne incognita* and growth parameters of brinjal. *Curr. Nematol.* 6: 21-26

Tiyagi, S. and Ajaz, S. 2004. Biological control of plant parasitic nematodes associated with chickpea using oil cakes and *Paecilomyces lilacinus*. *Indian J. Nematol.* 34: 44-48

Trivedi, P.C. and Goyal, S. 1998. Application of nematophagous fungi in the management of root-knot nematode infecting *Celosia argentea*. *J. Phytopath. Res.* 11: 69-72

Upadhyay, K.D. and Banerjee, B. 1986. Some chemical changes in chick pea plants infected with root knot nematode, *Meloidogyne javanica*. *Indian J. Nematol.* 16: 286-288

Vadhera, I., Tiwari, S.P. and Dave, G.S. 1998. Integrated management of root-knot nematode, *Meloidogyne incognita* in ginger. *Indian Phytopath.* 51: 161-163

*Vargas, R., Acosta, N., Monllor, A. and Betancourt, C. 1992. Control of *Meloidogyne* spp. with *Pasteuria penetrans* (Thorne) Sayre and Starr. *J. agric. Univ. Puerto-Rico* 76: 63-70

Vats, R., Singh, J. and Jain, R.K. 1998. Effect of few organic manures against root-knot nematode (*Meloidogyne incognita*) infecting cotton (*Gossypium hirsutum*). *Proc. nat. Symp. Rational Approaches Nematode Mgmt Sustainable Agric., 23-25 November 1998* (eds. Dhawan, S.C. and Kaushal, K.K). Gujarat Agricultural University, B.A. College of Agriculture, Anand, Nematological Society of India, Indian Agricultural Research Institute, New Delhi, pp. 10-12

Venkitesan, T.S. and Sethi, K.G.H. 1977. Pathogenicity of *Radopholus similis* to black pepper, *Piper nigrum*. *Indian J. Nematol.* 7: 17-26

Verma, A.C., Singh, H.K. and Khan, M.N. 2004. Management of root-knot nematode disease of brinjal and tomato through *Paecilomyces lilacinus*. Nat. Symp. Paradigms Nematological Res. Biodynamic Fmg, 17-19, November 2004. Nematological Society of India, University of Agricultural Sciences, Bangalore. *Abstract*: 64

Vidya, K. and Reddy, B.M.R. 1998. Integrated management of *Radopholus similis* infecting banana using plant product, nematicide and biocontrol agents. *Mysore J. agric. Sci.* 32: 186-190

*Vito, M.D., Zaccheo, G., Catalano, F., Campanelli, R. and Gullino, M.L. 2000. Effect of soil solarization and low doses of fumigants on the control of root-knot nematode *Meloidogyne incognita*. *Proc. Fifth int. Symp. Chem. Non-chem. Soil Substrate Disinfection, 11-15 September 2000* (eds. Katan, J. and Mafta, A.). Acta-Hort. 2000, Torino, Italy, pp. 171-173

Vyas, R. V., Patel N.N. and Patel, D.J. 1998. Integrated management of root-knot nematodes in cotton. *Proc. nat. Symp. Rational Approaches Nematode Mgmt Sustainable Agric., 23-25 November 1998* (eds. Dhawan, S.C. and Kaushal, K.K). Gujarat Agricultural University, B.A. College of Agriculture, Anand, Nematological Society of India, Indian Agricultural Research Institute, New Delhi, pp. 51-52

Walia, R.K. and Dalal, M.R. 1994. Efficacy of bacterial parasite *Pasteuria penetrans* application as nursery and soil treatment in controlling root-knot nematode, *Meloidogyne incognita* on tomato. *Pest Mgmt Economic. Zool.* 2: 19-21

Walia, R.K. and Mehta, S.K. 2000. Efficacy of *Pasteuria penetrans* against *Meloidogyne incognita* on okra under different adaphic factors. Nat. Nematology Symp. Integrated Nematode Mgmt Sustainable Agric. Changing Agro-ecol Econ. Scenario New Millennium, 23-24 November 2000. Orissa University of Agricultural Science and Technology, Bhubaneshwar. Nematological Society of India, Indian Agricultural Research Institute, New Delhi. *Abstract*: 56

Ward, and Pigman, 1970. *Analytical methods for carbohydrates*. The carbohydrates Vol. II B. Academic Press, New York, pp. 101-145

Watson, J.I. 1958. The physiological basis of variation for yield. *Ann. Bot.* 4: 101-145

Yadav, B.D. and Mathur, B.N. 1993. Reaction of chilli genotypes to root-knot nematode, *Meloidogyne incognita*. *Indian J. Mycol.* 23: 92-93

Yadav, B.D. and Mathur, B.N. 1999. Assessment of yield losses due to root-knot nematode, *Meloidogyne incognita* in green chillies in India. *Ann. Pl. Prot. Sci.* 7: 71-74

Zaki, F.A. 1998. Biological control of *Meloidogyne javanica* in tomato by *Paecilomyces lilacinus* and castor. *Indian J. Nematol.* 28: 132-139

Zaki, M.J. and Maqbool, M.A. 1990. Effect of *Pasteuria penetrans* and *Paecilomyces lilacinus* on the control of root-knot nematodes of brinjal and mung. *Pakist. J. Phytopath.* 2: 37-42

Zuckerman, B.M., Dicklow, M.B., Acosta, N. 1993. A strain of *Bacillus thuringiensis* for the control of plant parasitic nematodes. *Biocontrol Sci. Technol.* 3 : 41-46

---

*Original not seen

Appendix

APPENDIX – 1

Nutrient agar

Peptone	–	5 g
Agar agar	–	15 g
Beef extract	–	3 g
Sodium chloride	–	2 g
Distilled water	–	1000 ml
pH	–	6.8

Martin's Rose Bengal Agar medium

Peptone	–	5 g
Potassium dihydrogen phosphate	–	1 g
Magnesium sulphate	–	0.5 g
Dextrose	–	10 g
Rose bengal	–	33 g
Agar agar	–	15 g
Distilled water	–	1000 ml
pH	–	6.65

Potato Dextrose Agar

Peeled potato	–	200 g
Agar	–	20 g
Dextrose	–	20 g
Distilled water	–	1 l

INTEGRATED MANAGEMENT OF ROOT-KNOT NEMATODE, *MELOIDOGYNE INCOGNITA* (KOFOID & WHITE) CHITWOOD IN COLEUS, *SOLENOSTEMON ROTUNDIFOLIUS* (POIR) MORTON

NISHA, M.S.

Abstract of the
thesis submitted in partial fulfilment of the requirement
for the degree of

Doctor of Philosophy in Agriculture

Faculty of Agriculture
Kerala Agricultural University, Thrissur

2005

Department of Agricultural Entomology
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM-695 522

ABSTRACT

The root-knot nematode, *Meloidogyne incognita* (Kofoid and White) Chitwood is a serious pest in coleus, *Solenostemon rotundifolius* Poir (Morton) causing damage to tubers both in field and storage. A detailed study was undertaken at College of Agriculture, Vellayani during 2002-2005 to evolve an integrated management strategy in coleus. Experiments were carried out to find out the extent of crop loss under micro plot and storage conditions, biochemical changes due to *M. incognita* infestation in tubers, to identify the varietal resistance and to select effective treatments in nursery (physical methods, bioagents and organic amendments) and main field (bioagents and organic amendments singly and in combination).

Crop loss studies conducted under microplot condition indicated that there was significant reduction in biometric characters at monthly intervals from lowest inoculum level of 100 J_2 onwards. The yield attributing characters also showed significant reduction at 100 J_2 level (15.77 to 19.13 per cent). In the case of nematode population, there was progressive increase in recovery as the initial inoculum level increased from 100 to 5000 J_2. Crop loss studies under storage condition revealed that tubers obtained from 5000 and 1000 J_2 inoculated plants started rotting and get deteriorated at 15 and 45 days after storage respectively. The stored tubers from 500 J_2, 100 J_2 and uninoculated plants exhibited a weight loss of 96.50, 86.50 and 12.50 per cent respectively at three months after storage. Germination percentage of tubers collected from 100 and 500 J_2 inoculated plants showed 42.37 and 7.47 reduction respectively over the uninoculated at three months after storage. The vigour of the plants in terms of biometric characters also reduced significantly at the lowest inoculum level of 100 J_2.

The biochemical changes of tubers collected from plants inoculated with different levels of *M. incognita* revealed significant reduction in starch, sugar and crude fibre content. The percentage reduction being 6.32 to 33.33, 8.06 to 17.47 and 18.99 to 62.03 respectively as the population of nematodes increased from 100 to 5000 J_2. However, there was slight increase in protein content from 12.94 to 14.42 per cent.

Results on the resistance of coleus varieties/lines/accessions against *M. incognita,* established that variety Sree Dhara performed better in reducing the multiplication of nematodes in soil, root and tuber and production of root-knots, females, egg masses and eggs per egg mass. However in the case of total, marketable and edible portion weight of tubers, the performance of variety Sree Dhara and Nidhi was statistically on par. Based on the statistical superiority of the variety Sree Dhara to resist nematode infestation and numerically higher yield than Nidhi, Sree Dhara was selected as the resistant variety and included as a component in ensuing integrated nematode management study in coleus.

The evaluation of various treatments in the nursery revealed that soil solarization using 150 guage LDPE film for 15 days or application of bioagent *viz., Paecilomyces lilacinus* or *Bacillus macerans* @ 30 g m^{-2} significantly reduced the number of larvae, root-knots and egg masses in root (65.74 to 90.75 per cent reduction over the untreated). The reduction in *M. incognita* population contributed significant improvement in biometric characters which in turn resulted healthy vigorous cuttings of *S. rotundifolius* for transplantation. Thus soil solarization and application of either *P. lilacinus* or *B. macerans* were selected as nursery treatments for further investigations.

Among the main field treatments, application of *P. lilacinus* (15 g m^{-2}) in combination with either neem cake (100 g m^{-2}) or *B. macerans* (15 g m^{-2}) significantly reduced *M. incognita* population and improved the biometric characters, yield and quality parameters of *S. rotundifolius*. The

treatment combinations, *P. lilacinus* + neem cake and *P. lilacinus* + *B. macerans* showed 81.42 and 71.58 per cent increase respectively in total weight of tubers when compared to untreated.

In integrated management, the selected treatments in the nursery and mainfield were evaluated using the resistant variety Sree Dhara. Based on the overall performance in reduction of nematode population (soil and root), the improvement of biometric characters and yield of coleus tubers, integration of soil solarization in nursery for 15 days with 150 guage LDPE film and main field application of *P. lilacinus* (15 g m^{-2}) in combination with either neem cake (100 g m^{-2}) or *B. macerans* (15 g m^{-2}) were the best treatments for recommendation in the integrated nematode management strategy in *S. rotundifolius*. This strategy protected the crop against *M. incognita* and improved the per ha yield to a tune of 64.33 to 66.18 per cent. In addition to this, by reducing the nematode population in root (97.89 to 99.73 per cent), the quality parameters of tubers like starch, sugar and crude fibre content were also maintained.