Bangladesh J. Bot. **45**(5): 1003-1013, 2016 (December)

EVALUATION OF FUNGAL (*PAECILOMYCES LILACINUS*) FORMULATIONS AGAINST ROOT KNOT NEMATODE INFECTING TOMATO

PURA HANO AND MATIYAR RAHAMAN KHAN*

Department of Agricultural Entomology, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia-741252, West Bengal, India

Key words: Paecilomyces lilacinus, Root knot nematode, *Meloidogyne incognita*, Tomato

Abstract

Trials in both pot and field conditions for two consecutive seasons indicated that *Paecilomyces lilacinus* (PL)-formulation (25% SC/25% WP) was effective at different doses to reduce population of *Meloidogyne incognita* infesting tomato. A considerable reduction of soil nematode population was recorded; 25 - 86% in PL-formulations and 60 - 80% in carbofuran treated pots. Further, use of PL-formulations improved plant growth, fresh and dry weight of root and shoot. No significant impact of treatments on the root galling severity on tomato was observed. Field results showed that application of the PL 25WP at 1.5 kg in 500 kg FYM at transplanting and second application at same dose after 30 days of first application proved effective for reduction of nematode population (~24.50%) in soil and enhancement of yield by 60%. The treatment was considered as most economical for harvesting better tomato yield in the nematode infested fields. However, efficacy of PL-formulations was not as effective as carbofuran at 2.0 kg a.i./ha for root knot nematode management in tomato.

Introduction

Tomato (*Solanum esculentum* Mill.) is cultivated all over the world for its high nutritive and medicinal values. Among the vegetable crops, tomato supports wide range of pests including nematodes, pathogens, insects and other arthropods. Among the biotic stress in the crop production, plant parasitic nematodes are one of major concerns in the tropical and subtropical parts of the world. Plant parasitic nematodes are responsible for annual crop losses ranging from 8.8 - 14.6% (Sasser and Freckman 1987) of total crop production and the estimated monetary loss cited in many literatures between 100 and 157 US $ billion worldwide (Koenning *et al*. 1999, Thoden *et al*. 2011). Root knot nematodes (*Meloidogyne* spp.) stand out as one of most destructive nematodes in agriculture, causing an estimated yearly crop loss of US $ 100 billion worldwide (Oka *et al*. 2000). It can cause over 30% yield losses in vegetables (Netscher and Sikora 1990) and as high as 85% in tomato (Lamberti 1979). All the major species of root knot nematode and their races heavily attack tomato crop both in open-field and protected systems. Nematode can complete quickly life cycle within a short period on susceptible crop such as tomato and build-up generally to a maximum during its maturity (Davise *et al*. 1991) and often plants die before attaining maturity (Hague and Gowen 1987). Root knot nematode can cause extensive damage to a wide range of crops including many vegetables (Sasser 1989). In India, yield losses due to the infestation of root knot nematode in tomato range from 40 to 46% (Bhatti and Jain 1977). At the inoculum level of *M. incognita* @ 3 - 4 larvae/g soil, the yield loss of okra, tomato and brinjal were 90.9, 96.2 and 27.3%, respectively (Bhatti 1994). Nematicides have been considered as expensive means for controlling nematodes in developing countries and their application has been limited to few crops (Hague and Gowen 1987). Further, the hazardous effects of pesticides have increased research interest in biological control with a view to achieving environmentally safe method of

*Author for correspondence: Division of Nematology, Indian Agricultural Research Institute, New Delhi-110 012, India. <drmrkhanbckv@gmail.

reducing the nematode damage (Davise *et al*. 1991). *Paecilomyces lilacinus* (PL), an opportunistic fungus has been established as a potential biocontrol agent for controlling *Meloidogyne* spp., *Globodera rostochiensis*, *G. pallida*, *Tylenchulus semipenetrans*, *Rotylenchulus reniformis* etc. in wide range of crops (Jatala *et al*. 1979, Reddy and Khan 1988, Noe and Sasser 1995, Rao *et al*. 2012). Several efforts have been made to multiply this fungus on bulky substrates such as rice, neem cake, leaf residues, wheat bran etc., however, practical difficulties exist with these heavy materials along with uncertainty on viability of propagules in storage conditions. The commercial formulations of *P. lilacinus* are only viable options for making it easily available and economically viable. Therefore, the present study focused on understanding efficacy of *P. lilacinus* of two formulations (25% SC and 25%WP) at different doses in farm yard manure (FYM) supplemented conditions.

Materials and Methods

Experiments were carried out to understand the effects of commercial formulations of *Paecilomyces lilacinus* (PL-formulations) at different doses on root knot nematode (*Meloidogyne incognita*) infecting tomato in comparison to carbofuran 3G at 2.0 kg a.i./ha and untreated control in FYM supplemented (at 500 kg/ha) field conditions of West Bengal. All the treatments received 500 kg FYM/ha as basal application. The efficacies of treatments were evaluated two consecutive seasons both in pot and field conditions during 2012 to 2014. Pot experiment was carried out in a net-house in the Directorate of Research, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Kalyani, Nadia, West Bengal. For pot experiment, a soil-mixture was prepared with sandy soils of desired quantity and organic matters (FYM) in the proportion of 10 : 1 (v/v) over a polythene sheet in the net-house and mixed thoroughly before use. Soil-mixture was then drenched with formaldehyde 37% solution (1 part formaldehyde in 5 parts water) and soaked thoroughly, covered with a polythene sheet at least for 7 days to ensure adequate fumigation of soil mass. The polythene cover was removed after two weeks of fumigation, soil mass was opened up and spread on the sheet to release formaldehyde from the soil and dried for another 10 - 15 days before work up. This fumigated soil was considered as sterile soil for filling of earthen pots, each pot contained 8.0 kg soil mixed well with 25 g FYM. Each pot was planted with susceptible hosts (okra/brinjal) for development of soil population (J_2-second stage juvenile of *M. incognita* race 2) during off-season. Initial nematode population (INP) of about 250 - 300 J_2/200 cm^3 soil was ensured before the start of the experiment with the growing of tomato plants. The experimental treatments comprised of T1= *Paecilomyces lilacinus*-PL25%WP @ 1.0 kg in 500 kg FYM/ha, T2 = PL25% WP @ 1.5 kg in 500 kg FYM/ha, T3 = PL25%WP @ 2.0 kg in 500 kg FYM/ha,T4 = PL 25% SC @ 1.0 lit in 500 kg FYM/ha, T5 = PL25%SC @ 1.5 lit in 500 kg FYM/ha,T6 = PL25% SC @ 2.0 lit in 500 kg FYM/ha, T7 = carbofuran (furadan 3G) @ 66.6 kg in 500 kg FYM/ha, and T8 (untreated control) @ 500 kg FYM/ha. The second treatment with same dosage of PL 25% WP and PL 25% SC formulations was made after 30 days of the first treatment. The viable spore count (CFU/g) in PL formulations was a minimum of 2×10^6. Earthen pots were arranged on a cement-floor in randomized block design (RBD). All the eight treatments had four replications. A three-week-old tomato seedling (cv. *Pathar kuchi*) was transplanted during November months of 2012 and 2013. The plants received necessary care for adequate watering and maintenance of weed free conditions. The observation on plant height (30 and 60 days after transplanting), root galling severity (RGS) on a 1 - 5 scale: 1 = No galls; 2 = 2-10, 3 = 11 - 30 galls; 4 = 31 -1 00; 5 = >100 galls per root system, final nematode population (per 200 cm^3 of soil + 5 g root), fresh and dry weight (g) of shoot and root at final harvest were recorded.

Field experiment was carried out in a sick-plot which was previously infested with *M. incognita* at the Central Research Farm of BCKV, Gayeshpur, Nadia, West Bengal. The farm is located at 23^0 N latitude and 89^0 E longitudes at an elevation of 9.75 meter from the mean sea level. The land is topographically designated as medium land. The field plots were previously grown with susceptible tomato cultivar (*Pathar kuchi*) over five years and thus the soil was naturally infested with *M. incognita*. The soil type of the field in which the experiments was carried out, was typically Gangetic New Alluvial soil having sandy-clay-loam texture with good drainage facility, neutral in reaction and moderate in fertility. The weather conditions during experimental period can be characterized by having total rainfall of 97.4 mm, temp-max 24.8 - 37.3°C; temp.-min 9.6 - 22.5°C, and relative humidity (RH)-max 88.5-95.3, RH-min 34.2 - 59.20 during 2012 - 2013, whilst in 2013 - 2014 total rainfall was 80.20 mm, temp.-max. 24.5 - 33.5°C, temp.-min 10.4 - 23.90°C; RH-max 83.8 - 96.9%, RH-min 46 - 78.8%. Experimental field was with uniform infestation of root knot nematode as stated above. After the proper land preparation, the experimental field was divided into 32 plots, each plot measuring 3 m × 2 m with a requisite buffer area 0.5 m × 0.5 m between the plots. Plots were laid out in RBD. Eight treatments were distributed in 32 plots in such a way that each treatment comprised of four replications. FYM was broadcasted in each plot and mixed with soil. The tomato seedlings (cv. *Pathar kuchi*) was transplanted with a row spacing of 60 cm and plant spacing of 40 cm, 25 plants were maintained per plot. Agronomic practices and organic fertilizers (NPK) were applied as per recommendations for the crop in the region. *P. lilacinus* formulations were procured from SRT Crop Science Ltd., treatments were designed with a standard check (carbofuran 3G, FMC Rallis India Ltd.) and FYM (procured from local farmer). Tomato fruits were harvested at regular interval, yield data were collected from each plot, and computed yield from each treatment and plot subjected for statistical analysis. Soil and root samples from each plot were collected during final harvest for estimation of final nematode population. The root gall severity (RGS) was recorded on a 1 - 5 scale, soil (200 cm^3) along with root (5 g) samples was collected separately from the experimental plots/pots around the rhizosphere of tomato for each treatment during final harvesting. Samples from all replications were collected in the polythene bags separately with appropriate tags, they were processed immediately in the laboratory. Nematodes were extracted from soil (200 cm^3 composite) samples by Cobb's decanting sieving technique (Cobb 1918) followed by modified Baermann's technique (Whitehead and Hemming 1965) and from root (5 g) samples by the later method. Nematode specimen were killed by hot-water bath method - a glass beaker containing nematode suspension of a specific sample was plunged in hot-water kept on hot-plate and shaken for uniform bathing of nematodes for 2 - 4 min at 65^0C. The nematode suspension was kept out of hot-plate to bring the suspension at room temperature and to allow the nematodes for settling at the bottom of glass beaker (250 ml). The top half of water was carefully removed with the help of dropper, thus concentrated nematodes were mixed with double strength FA (4 : 1) for preservation of nematode specimens. Each suspension was stored separately in a plastic bottle with proper labeling for further study. Fixed nematode suspension was made to a volume of 100 ml by adding water measuring with help of measuring cylinder. This was thoroughly mixed up, 5 ml of nematode suspension was transferred to a multi-chambered counting disc, and counted under the stereoscopic microscope (OLYMPUS SZ-7). The mean number of three aliquots was taken to determine total nematode population per 200 cm^3 soil or 5 g roots for each sample. The species of root knot nematode infecting tomato was confirmed by studying perineal patterns of mature females. The data recorded during the experiment were subjected to appropriate statistical analysis for interpretation of field results. Computer software like MSTAT-C and MS-Office-excel sheet was used for calculation and analysis of experimental data.

Results and Discussion

Results of pot experiment during *rabi* season (September-March) of 2012-2013 are presented in Table 1. Results showed that application of PL-formulations caused substantial improvement of plant growth and reduction of soil nematode (J_2) population. However, root galling severity (on 1 - 5 scale) on tomato was found to be relatively high in PL-treated pots in comparison to carbofuran. No significant effects of treatments on the fresh and dry weight of root and shoot of tomato were found. During harvesting of plants, the final population recovered from the soil and roots showed considerable reduction of soil nematode (J_2) population - 25 to 58% in PL-formulations and 60% in carbofuran treated pots.

The same experiment was repeated during *rabi* season (September-March) of 2013 - 2014 on tomato under similar conditions. The results (Table 2) were almost similar all the PL-formulations at different doses improved plant growth, fresh and dry weight of root and shoot, and suppression of soil nematode (J_2) population. No significant impact of any treatment on the root galling caused by *M. incognita* in tomato was observed. However, considerable reduction of soil nematode population was recorded - 48 to 86% in the PL-formulations and 83% in carbofuran treated pots.

Field evaluation of *P. lilacinus* formulations was also done against *M. incognita* infecting tomato in a sick-plot. Results showed that application of the PL 25WP at 1.5 kg in 500 kg FYM at transplanting and second application of product formulations at same dose after 30 days of first application (= T_2) proved effective for reduction of nematode population (~24.50%) in soil and enhancing yield to extent of 60% during 2012 - 2013 (Table 3). In terms of yield benefit, this treatment was found at par with the efficacy of PL 25SC at 2.0 lit in 500 kg FYM (= T6) and carbofuran 3G at 2.0 kg a.i. (Table 1). The greatest reduction (~60%) of soil nematode population was achieved with the application of PL 25SC at 2.0 lit in 500 kg FYM (= T6) followed by PL 25% WP at 2.0 kg in 500 kg FYM (= T3). However, application of carbofuran 3G at 2.0 kg a.i. was not effective enough to prevent nematode multiplication. In this experiment, infestation of root knot nematode in tomato was recorded as severe (gall index >3.60) - the infested plants showed profuse root galling at the harvest of the crop. Calculation of incremental cost benefit ratio (ICBR) revealed that order of economic benefit of treatment as T_2 (~42.04), T_6 (~23.92), T_1(~19.21) and T_3(~18.68).

The same experiment was repeated during 2013 - 2014 on the same field with the initial nematode population density of 280 per 200 cm^3 soil. The application of PL-formulations failed to reduce root galling severity in tomato (Table 4). However, reduction of nematode population (J_2) in the soil was as high as 64% and as low as 24%. This highest reduction was achieved with the application of T_4 (PL 25% SC + 1.0 lit in 500 kg FYM). Among the treatments, the highest tomato yield (14.02 kg/plot) was achieved with the application of carbofuran (2.0 kg a.i./ha). However, almost similar yield was obtained with the application of T_1 (PL 25% WP + 1.0 kg in 500 kg FYM) and T_2 (PL25% WP +1.5 kg in 500 kg FYM). The ICBR values of T_1 and T_2 (20.39 vs 27.05) were quite higher than that of other treatments. Therefore, T_2 could be considered as most economical treatment for harvesting better tomato yield in nematode infested fields. Considering ICBR alone, T_2 (~27.05) was most economical followed by T_1 (~20.39), T_4 (~13.06) and T_6 (~10.75).

Both pot and field trial results further proved biocontrol potential of *P. lilacinus* against root knot nematodes. In fact, *P. lilacinus*, an opportunistic fungus has been extensively studied for controlling root knot nematode (*M. incognita*) in diverse crops. It can act on nematodes by several means. The fungus is capable of colonizing on nematode egg mass and female body - thereby causing destruction of females, cysts and eggs (Jatala 1986, Cardona and Leguizamon 1997, Azam *et al*. 2013). The mode of action for the control of nematodes is primarily through colonization on

Table 1. Effects of treatments on root knot nematode (*Meloidogyne incognita*) infecting tomato in 2012 - 2013 under pot conditions.

Treatments	First dosage /ha	Second dosage (30 DAFT)/ha	Gall index (1-5)	Plant height (cm) after		Shoot weight (g)		Root weight (g)		FNP	Per cent reduction over control
				30 DAT	60DAT	Fresh	Dry	Fresh	Dry		
T_1 = PL25% WP	1.0 kg in 500 kg FYM	1.0 kg	3.67	27.83 ± 0.93	55.10 ± 1.17	137.34	22.70	31.77	5.80	717.6	52.10
T_2 = PL 25% WP	1.5 kg in 500 kg FYM	1.5 kg	3.50	33.67 ± 3.52	62.33 ± 3.84	128.85	24.91	33.39	5.90	622.6	58.44
T_3 = PL 25% WP	2.0 kg in 500 kg FYM	2.0 kg	4.17	34.50 ± 3.50	56.33 ± 5.37	163.24	29.80	57.58	11.71	822	45.13
T_4 = PL 25% SC	1.0 lit in 500 kg FYM	1.0 lit	3.83	32.50 ± 1.01	45.50 ± 2.52	133.99	21.65	55.85	10.41	796.4	46.84
T_5 = PL 25% SC	1.5 lit in 500 kg FYM	1.5 lit	4.33	39.00 ± 3.81	55.33 ±4 .24	163.96	27.21	38.21	11.71	868.2	42.04
T_6 = PL 25% SC	2.0 lit in 500 kg FYM	2.0 lit	3.33	31.17 ± 3.73	40.83 ± 1.58	165.35	32.73	61.08	12.89	1122.2	25.09
T_7= Carbofuran 3G	66.6 kg in 500 kg FYM	66.6 kg	2.33	32.00 ± 2.77	60.17 ± 0.25	171.12	30.19	48.61	10.12	602.4	59.79
T_8 = Untreated control (FYM only)	500 kg FYM	-	4.67	22.17 ± 5.14	34.00 ± 0.17	134.02	24.40	21.63	4.80	1498	-
SEM (±)	-	-	0.37	ns	4.64	-	-	-	-	-	-
CD ($p < 0.05$)	-	-	1.07	-	13.64	-	-	-	-	-	-

Initial nematode population = 210 per 200 cm^3 soil ; DAFT- days after first treatment; FNP = final nematode population per 200 cm^3 + 5 g root; date of planting: 23.12.2012, date of final harvesting: 11.03.2013.

Table 2. Effects of treatments on root knot nematode (*Meloidogyne incognita*) infecting tomato in 2013 - 2014 under pot conditions.

Treatments	First dosage /ha	Second dosage (30 DAFT)/ha	Gall index (1-5)	Plant height (cm) after		Shoot weight (g)		Root weight (g)		FNP	Percent reduction over control
				30 DAT	60 DAT	Fresh	Dry	Fresh	Dry		
T_1 = PL 25% WP	1.0 kg in 500 kg FYM	1.0 kg	4.25	31.50 ± 0.66	39.50 ± 0.97	220.00 ± 29.58	24.71 ± 3.05	15.24 ± 2.24	3.26 ± 0.23	440	74.71
T_2 = PL 25% WP	1.5 kg in 500 kg FYM	1.5 kg	3.25	30.50 ± 1.48	49.25 ± 4.76	167.75 ± 17.28	16.70 ± 3.75	23.94 ± 2.00	3.57 ± 0.37	250	85.63
T_3 = PL 25% WP	2.0 kg in 500 kg FYM	2.0 kg	4.75	30.50 ± 0.32	39.50 ± 1.61	147.75 ± 9.05	32.25 ± 3.46	18.83 ± 0.39	2.81 ± 0.10	520	70.11
T_4 = PL 25% SC	1.0 lit in 500 kg FYM	1.0 lit	4.50	31.00 ± 2.58	43.00 ± 2.16	177.75 ± 21.31	22.94 ± 3.71	20.40 ± 1.48	2.72 ± 0.33	905	47.99
T_5 = PL 25% SC	1.5 lit in 500 kg FYM	1.5 lit	3.50	31.50 ± 0.63	39.75 ± 0.69	163.25 ± 11.32	22.99 ± 2.24	15.26 ± 0.83	2.51 ± 0.17	260	85.06
T_6 = PL 25% SC	2.0 lit in 500 kg FYM	2.0 lit	4.50	26.50 ± 0.25	33.00 ± 0.74	133.00 ± 10.07	20.64 ± 0.58	14.86 ± 0.37	1.43 ± 0.24	280	83.91
T_7 = Carbo-furan 3G	66.6 kg in 500 kg FYM	66.6 kg	3.50	26.75 ± 1.13	41.75 ± 2.01	167.50 ± 15.20	23.63 ± 2.96	8.41 ± 0.47	1.97 ± 0.26	290	83.33
T_8 = Un treated control	500 kg FYM	-	4.75	23.00 ± 0.89	32.75 ± 1.01	11.25 ± 1.20	1.79 ± 0.15	5.64 ± 0.21	1.29 ± 0.02	1740	-
SEM (±)	-	-	ns	1.65	4.34	29.39	5.57	2.56	0.43	-	-
CD ($p < 0.05$)	-	-	-	4.85	12.79	86.42	16.39	7.53	1.25	-	-

Initial nematode population = 235 per 200 cm^3 soil; DAFT = days after first treatment; FNP = final nematode population per 200 cm^3 + 5 g root; date of planting: 26.11.2013, date of final harvesting: 17.03.2014.

Table 3. Effects of treatments on root knot nematode (*Meloidogyne incognita*) infecting tomato in 2012 - 2013 under field conditions.

Treatments	First dosage/ ha	2nd dosage application (30 DAFT)/ha	Gall index (1 - 5)	Final nematode population (/200 cm^3 + 5 g root)	% reduction over control	Yield (kg/plot)	Yield (t/ha)	ICBR
T_1 = PL 25% WP	1.0 kg in 500 kg FYM	1.0 kg	4.05a*	650	46.90	6.04bc	15.10	19.21
T_2 = PL 25% WP	1.5 kg in "	1.5 kg	4.11a	924	24.50	7.61d	19.02	42.04
T_3 = PL 25% WP	2.0 kg in "	2.0 kg	4.60a	612	50.00	6.14c	15.34	18.68
T_4 = PL 25% SC	1.0 lit in "	1.0 lit	4.31a	994	18.79	4.47b	11.17	–5.86
T_5 = PL 25% SC	1.5 lit in "	1.5 lit	4.06a	869	29.00	4.94ab	12.36	1.40
T_6 = PL 25% SC	2.0 lit in "	2.0 lit	3.60b	484	60.46	6.58cd	16.46	23.92
T_7 = Carbofuran 3G	66.6 kg in "	66.6 kg	4.41a	1177	3.84	6.43cd	16.08	6.08
T_8 = Untreated control	500 kg FYM	-	4.75a	1224	-	4.75ab	11.95	-
SEM (±)	-	-	0.23	-	-	0.47	-	-
CD ($p < 0.05$)	-	-	0.66	-	-	1.37	-	-

Initial nematode population 280 per 200 cm^3 soil; DAFT- days after first treatment; J_2 - second stage juvenile; NS - non-significant: date of planting: 17.10.2012; date of final harvesting: 26.03.2013.

Table 4. Effects of treatments on root knot nematode (*Meloidogyne incognita*) infecting tomato in 2013 - 2014 under field conditions.

Treatments	First dosage/ ha	2nd dosage application (30 DAFT)/ha	Gall index (1-5)	Final nematode population (/200 cm^3 + 5 g root)	% reduction over control	Yield (kg/plot)	Yield (t/ha)	ICBR
T_1 = PL25% WP	1.0 kg in 500 kg FYM	1.0kg	4.15ab*	360	28	12.78bc*	21.29	20.39
T_2 = PL 25% WP	1.5 kg in "	1.5kg	3.35a	380	24	13.54b	22.56	27.05
T_3 = PL 25% WP	2.0 kg in "	2.0kg	3.60a	300	40	11.11ad	18.52	2.26
T_4 = PL 25% SC	1.0 lit in "	1.0 lit	3.70a	180	64	12.13acd	20.21	13.06
T_5 = PL 25% SC	1.5 lit in "	1.5 lit	3.65a	170	46	11.15ad	18.58	2.67
T_6 = PL 25% SC	2.0 lit in "	2.0 lit	3.65a	340	32	12.05acd	20.08	10.75
T_7 = Carbofuran 3G	66.6 kg in "	66.6 kg	3.75a	280	44	14.02b	23.67	8.79
T_8 = Untreated control	500 kg FYM	-	4.55b	500	-	10.78d	17.96	-
SEM (±)	-	-	0.23	-	-	0.54	-	-
CD ($p < 0.05$)	-	-	0.67	-	-	1.60	-	-

Initial nematode population = 250 per 200 cm^3 soil; DAFT - days after first treatment; J2 - second stage juvenile; date of planting: 15.10.2013; date of final harvesting 30.03.2014. *DMRT test - Means followed by the same letter within each column are not significantly different ($p = 0.05$).

root of tomato as well as on egg mass of *M. incognita*. The fungus could prevent giant cell formation and development of root galling in tomato root (Cabanillas *et al*. 1988). As an efficient egg parasitic fungus, the reduction of root knot nematode population in soil was probably due to destruction of eggs in the eggmass. Further, the fungus is capable of incapacitating second stage juveniles, the infective stage of the root knot nematode and infecting mature females (Jatala 1986, Azam *et al.* 2013). The filtrates of *P. lilacinus* inhibit hatching of eggs in eggmass and the fungal filtrate was proved to be nematicidal (Khan and Goswami 1999). The present study demonstrates appreciable reduction of root knot nematode population both in pot and field conditions with the application PL-formulations at different doses. Similar results were also reported (Sharma *et al.* 2007, Khalil *et al*. 2012) where application of *P. lilacinus* reduced the number of galls in tomato and soil nematode population. The reduction of soil population of *M. incognita* with increase of tomato yield was demonstrated (Lara *et al*. 1996). The talc-based formulation (at 8×10^6 spores/g) of *P. lilacinus* when applied as seed treatment, seedling-dip and soil application was found to be highly effective against *M. incognita* on tomato (Priya and Kumar 2006). There are several studies reporting efficacy of *P. lilacinus* as comparable to that by the application of carbofuran (Walia *et al*. 1999), nemacur (Oclarit and Cumagun 2009) and oxamyl (Anastasiadis *et al.* 2008). However, the results of the present study reveal that the PL-formulations both in suspension concentrates (25% SC) and wettable powder (25% WP) are effective in reducing nematode population in soil, improving plant growth parameters and enhancing tomato yield. Pot and field evaluations of treatments show consistency in results in terms of efficacy of PL-formulations. Some variations in results are noted, those presumably are due to the seasonal effects and establishment of fungus in the soil and crop environment. These are only speculations but difficult to correlate with causal factors. The present study demonstrates well that *P. lilacinus* formulations (both SC and WP) are effective enough in managing root knot nematode problems in tomato and the results often show comparable to that by carbofuran. The efficacy of *P. lilacinus* has always been compared with carbofuran at 1.0 - 2.0 kg a.i./ha and the results in PL has in most cases proved as effective as chemical treatment and in some cases superior to carbofuran.

As PL-products are ecofriendly, this could be an alternative of chemicals and may be combined with chemicals such as carbofuran, carbosulfan etc., (Singh *et al*. 2009, Fazal *et al*. 2011) and neem cake (Sharma *et al.* 2007) for improving effectiveness in the integrated management of root knot nematodes. Further, multiple applications of *P. lilacinus* (Jatala *et al*. 1981) in different crops in crop sequences would pay dividend to the growers for long-term and sustainable production of crops.

Acknowledgements

Authors are thankful to the Directorate of Research, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Kalyani, West Bengal for providing facilities at the Directorate and Central Research Farm, BCKV for carrying out this investigation.

References

Anastasiadis IA, Giannakou IO, Prophetou-Athanasiadou DA and Gowen SR 2008. The combined effect of the application of a biocontrol agent *Paecilomyces lilacinus*, with various practices for the control of root-knot nematodes. Crop Protec*.* **27**: 352-361.

Azam T, Akhtar MS and Hisamuddin 2013. Histological interactions of *Paecilomyces lilacinus* with root knot nematode *Meloidogyne incognita* and their effect on the growth of tomato. American Scientific Publishers, California, USA, Advanced Science, Engineering and Medicine (ASEM). pp. 335-341.

Bhatti DS 1994. Management of phytonematodes - An introduction. pp. 1-6. *In*: Nematode pest management in crops (Bhatti, D.S. and Walia, R.K. Eds.), CBS Pub. and Distributors. Delhi.

Bhatti DS, and Jain RK 1977. Estimation of losses in okra, tomato and brinjal yield due to *Meloidogyne incognita*. Indian J. Nematol. **7**: 37-41.

Cabanillas E, Barker KR and Daykin ME 1988. Histology of the interactions of *Paecilomyces lilacinus* with *Meloidogyne incognita* on tomato. J. Nematol. **20**(3): 362-365.

Cardona BNL and Leguizamon CJE 1997. Isolation and pathogenicity of fungi and bacteria to the root knot nematode of coffee *Meloidogyne* spp. Goeldi. Fitopatologica Colombena **21**: 39-52.

Cobb NA 1918. Estimating the nema population of the soil. Agric. Tech. Circ. Bur. Pl. Ind. U.S. Dept. Agric. No. **1**. p. 48.

Davise KG, De Ley FAAM and Kerry BR 1991. TPM special review No. 4. Microbial agents for the biocontrol of plant parasitic nematodes in tropical agriculture. TPM **34**: 303-320.

Fazal M, Bhat MY and Ashaq M 2011. Combined application of *Paecilomyces lilacinus* and carbosulfan for management of *Meloidogyne incognita* and *Rotylenchulus reniformis.* Ann. Pl. Protec. Sci. **19**: 168-173.

Hague NMH and Gowen SR 1987. Chemical control of nematodes. *In*: Principles and practices of nematode control in crops, (Brown, R.H. and Kerry, B.R. Eds.). Sydney, Academic Press. pp. 131-178.

Jalata P 1986. Biological control of plant parasitic nematodes. Ann. Rev. Phytopathol. **24**: 453-489.

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

Jatala P, Sales R Kaltenback R. and Bocangel M 1981. Multiple application and long term effect of *Paecilomyces lilacinus* in controlling *Meloidogyne incognita* under field condition. J. Nematol. **13**: 445.

Khalil MS, Kenawy A Gohrab MA and Mohammed EE 2012. Impact of microbial agents on *Meloidogyne incognita* management and morphogenesis of tomato. J. Biopest. **5**: 28-35.

Khan MR and Goswami BK 1999. Nematicidal effect of culture filtrates of *Paecilomyces lilacinus* isolates on *Meloidogyne incognita.* Indian J. Nematol. **29**: 145-148.

Koenning SR, Overstreet C Noling JW Donald PA Becker JO and Fortnum BA 1999. Survey of crop losses in response to phytoparasitic nematodes in the United States for 1994. J. Nematol. **31**: 587-618.

Lamberti F 1979. Economic importance of *Meloidogyne* spp. in sub-tropical and Mediterranean climates. pp. 341-357. *In:* Root knot nematodes (*Meloidogyne* species), Systematic, Biology and Control. (Lamberti, F. and Taylor, C.E. eds), London, Academic Press.

Lara J, Acosta N Betancourt C Vincente N and Rodriguez R 1996. Biological control of *Meloidogyne incognita* in tomato in Puerto Rico. Nematropica **26**: 143-152.

Netscher C and Sikora RA 1990. Nematode parasites of vegetables. pp. 237-283. *In*: Plant parasitic nematodes in subtropical and tropical agriculture (Luc, M. Sikora, R. and Bridge, B. Eds.), Wallingford, Oxon, UK; CAB International.

Noe JP and Sasser JN 1995. Evaluation of *Paecilomyces lilacinus* as an agent for reducing yield losses due to *Meloidogyne incognita*. Biocontrol. **1**: 57-67.

Oclarit EL and Cumagun CJR 2009. Evaluation of efficacy of *Paecilomyces lilacinus* as biological control agent of *Meloidogyne incognita* attacking tomato. J. Pl. Protec. Res. **49**: 337-340.

Oka Y, Koltai H, Eyal BM, Mor M, Sharon E Chet I and Spiegel Y 2000. New strategies for the control of plant parasitic nematodes. Pest Manage. Sci. **56**: 983-988.

Priya MS and Kumar S 2006. Studies on the method of application of the fungus, *Paecilomyces lilacinus* against root knot nematode on tomato. Indian J. Nematol. **36**: 23-26.

Rao MS, Kumar DRM Chaya MK Grace GN Rajinikanth R Bhat A and Shivananda TN 2012. Efficacy of *Paecilomyces lilacinus* (1% WP) against *Meloidogyne incognita* on tomato in different agro-climatic regions in India. *Pest Manage.* Hortic. Ecosys. **18**: 199-203.

Reddy PP and Khan RM 1988. Evaluation of *Paecilomyces lilacinus* for the biological control of *Rotylenchus reniformis* infecting tomato, compared with carbofuran. Nematol. Medit. **16**: 113-115.

Sasser JN 1989. Plant parasitic nematodes, the farmer's hidden enemy. Coop Pub., Dept. PI. Pathol., North Carolina State University, USAID, Raleigh, NC, USA., pp: 13. SEM/1982/III. Scanning Electron Microscopy, Inc., Chicago, IL.

Sasser JN and Freckman DW 1987. A world perspective on nematology: The role of the Society. pp. 7-14. *In*: Vistas on Nematology: A Commemoration of the Twenty-Fifth Anniversary of the Society of Nematologists (Veech, J.A. and Dickson, D.W. Eds.), Society of Nematologists, Hyattsville, Maryland (US).

Sharma HK, Singh S and Pankaj 2007. Management of *Meloidogyne incognita* with *Paecilomyces lilacinus* and neem cake on okra. Pesticide Res. J. **19**: 166-68.

Singh M, Jain A and Gill JS. 2009. Dose optimization of egg parasitic fungus *Paecilomyces lilacinus* alone and in combination with carbofuran for control of *Meloidogyne incognita* infecting tomato. Int. J. Nematol. **19**(2): 177-181.

Thoden TC, Korthals GW and Termorshuizen AJ 2011. Organic amendments and their influences on plant-parasitic and free-living nematodes: A promising method for nematode management? Nematology **13**: 133-153.

Walia RK, Nandal SN and Bhatti DS 1999. Nematicidal efficacy of plant leaves and *Paecilomyces lilacinus* alone or in combination, in controlling *Meloidogyne incognita* on okra and tomato. Nematol. Medit. **27**: 3-8.

Whitehead AG and Hemming JR 1965. A comparison of some quantitative methods of extracting small vermiform nematodes from soil. Ann. Appl. Biol. **55**: 25-38.

(Manuscript received on 21 August, 2014; revised on 27 December, 2015)