Integrated Strategies to Managing *Meloidogyne Incognita* and Soil Borne Fungus Infesting Cucumber in Two Consecutive Crop Seasons Under Protected Cultivation

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Research Article

Keywords: Meloidogyne incognita, fungus, management, integration, Purpureocillium lilacinum and Cucumis sativus

Posted Date: June 1st, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-568988/v1>

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Abstract

Relative efficacy of various approaches to managing *Meloidogyne incognita* and soil borne fungus, *Fusarium oxysporum* f. sp. *cucumerinum* in cucumber for two seasons was tested under protected cultivation. Several management practices adopted such as chemicals (fumigant, non-fumigant, and fungicide), organic amendments (Neem cake, leaves and oil, soil and seed treatment), and biocontrol agents (the egg-parasitic fungus, *Purpureocillium lilacinum*), all practices combine for the management of disease. Eleven treatments with untreated control in a randomized block design. Two significant parameters were measured: plant growth parameter (plant height, dry root weight and yield) and disease parameters (galls/plant, final nematode population, egg masses/plant and fungal incidence). All treatments significantly improved plant growth parameters and reduced nematode reproduction as compared to untreated check. The integration of formalin and neem oil seed treatment favor the low root galling index compared to all other treatments in both the seasons. Integration of formalin and neem oil seed treatment reduced nematode population and fungus incidence and increased the yield of cucumber during both the seasons.

Key Message

- Application of fumigant nematicides is still the primary strategy to manage both pathogens *M. incognita* and *F. oxysporum* f. sp. *Cucumerinum* in cucumber under protected cultivation.
- Integration of formalin and neem oil was not only very effective against *M. incognita* and *F. oxysporum* but also its application showed prominent effect on the growth of cucumber.
- To our knowledge, this is the first study has been carried under the field conditions. Most of the study had conducted under laboratory and pot conditions.
- In this investigation, we confirmed that formalin and neem oil had high nematicidal activities against both pathogens and application of formalin and neem oil significantly enhanced cucumber yield in polyhouse.

Introduction

Cucumber (*Cucumis sativus* L.) is most widely cultivated crop under protected conditions in India and in all over the world. Cucumber is a good source of minerals, vitamins and fibers (Weng 2011). Continuous same crop with ideal temperature and relative humidity under polyhouse favor the nematodes and fungal diseases (Minuto et al. 2006; Patil et al. 2017a). Synergistic interaction between fungal pathogens and root-knot nematode possibly causes heavy losses to the host crop (Ragozzino and d'Errico 2012; Patil et al. 2018a). Furthermore, severe damping off and nematode disease complex symptoms have been reported in cucumber cultivating regions under polyhouse conditions. (Greco and Esmenjaud 2004; Patil et al. 2017b; Katan 2017) The damping off fungus could be affect the roots with fluctuating grades of harshness depends on, plant variety, environment, and soil texture. The soil temperature (up to 20–25° C) show a significant role in causes damping off disease due to *F. oxysporum*.

Though, root-knot nematode (*Meloidogyne incognita*) is the highly damaging plant-parasitic nematodes, infecting almost all the crops grown under protected cultivation (Sharma et al., 2007; Patil et al. 2017a; Greco and Esmenjaud 2004; Koenning et al. 1999; Murungi et al. 2018). In Haryana (India) under protected conditions root-knot nematode frequency of occurrence and density range were 63.15% and 30-10000 J₂ / 200 cc soil respectively (Patil et al. 2017). Plants infected with root-knot nematode shows typical galling on roots and express nutrient deficiency symptoms, mainly for nitrogen (Good, 1968; Kepenekci et al. 2016). Management of *Meloidogyne* spp. is very difficult due of their wide host parasitizing ability, short life cycle (within 20 to 25 days), high reproduction potential

and sedentary endo-parasitic nature (Mauchline et al., 2004). Nevertheless, effective approach to manage *Meloidogyne* spp. and *Fusarium* spp. by application of artificial chemicals (d'Errico et al. 2017; Giacometti et al. 2010). *M. incognita* is tough to manage with a solo management technique (Barker et al. 1985). The chemicals applied in crops are not always with competent effectiveness and much of their uses cause serious bionomic problems (Fàbrega et al. 2013). Therefore, new alternative methods have been used to manage *Meloidogyne* spp. and fungal pathogen in polyhouse conditions, including volatile and non-volatile nematicides, fungicide, organic amendments and bio-control strategies (Timper, 2011; Abd-Elgawad and Askary, 2018). Excellent and extensive research work has been conducted to manage root-knot nematode and soil born fungal pathogen on vegetable crops under protected conditions, including the soil solarization, soil fumigation, use of organic amendments (various cake and leaves), biocontrol agents (fungus and bacteria) (Patil et al. 2018a, 2018b; Collange, 2011; Mcsorley, 2011).

However, lesser work has been done for management of complex diseases in cucumber under protected cultivation. Aim of this study was to examine the integrated management strategies against *Meloidogyne incognita* and fungal pathogen in cucumber under polyhouse.

Materials And Methods

This investigation was conducted under protected cultivation system on cucumber (*Cucumis sativus* L.) during 2015-16 (from April 15th to 19th July, 2016) and 2016-17 (from August 25th to December 5th, 2016) at Department of Horticulture, CCS HAU, Hisar, Haryana, India (Latitude: 29°10'N, Longitude: 75°46'E, and Altitude: 215.2 m).

2.1. Materials used in experiment

A commercial bio-product containing *Purpureocillium lilacinus* (1% W.P.) (CFU of 2×10^6 /g) was procured from IIHR, Bengaluru and one synthetic nematicides (Carbofuran 3 G) and one synthetic fungicide (Bavistin) were used. Neem leaves first chop into small pieces with help of scissor or grinder. Neem cake and neem oil was available locally in the market. Product and their application detail have been described in Table 1. The following treatments were selected on the basis of results obtained in our pot study where large number of chemicals (Formalin, Dazomet, Carbofuran and Bavistin), organic amendments (Neem, Aak, Castor leaves, Neem seed kernel powder, Neem, Castor, Mustard cake, Neem, mustard and jatropha oil,), bioagents (soil as well as seed treatment with *Trichoderma viride*, *Pseudomonas fluorescence*, *Purpureocillium lilacinum* and liquid formulation *T. viride*+ *P. fluorescence*+ *P. lilacinus*) were tested for their efficacy against *Meloidogyne incognita* and *Fusarium oxysporum* f. sp. *cucumerinum* in cucumber under protected cultivation (Patil 2017c; Patil et al. 2018a and 2018b). Following best treatments were selected for this field.

Table 1
Different management practices and their application methods

Management strategies	Management method	Material used	Application methods	Time of application	Doses
Chemical	Fumigant	Formalin	Fumigation	Twenty days before sowing	30 % i.e. 250 ml/m ²
	Non-fumigant	Carbofuran	Soil application	Before sowing	10 g/m ²
	Fungicide	Bavistin	Drenching	Before sowing	2 g/l water
Biological	Egg-parasitic fungus	<i>Purpureocillium lilacinum</i>	Soil application	Fifteen days before sowing	50 g/m ²
			Seed treatment	Twelve hours before sowing	20 g/kg seed
Cultural	Organic amendment	Neem cake	Soil application	Fifteen days before sowing	200 g/m ²
		Neem leaves	Soil application	Fifteen days before sowing	200 g/m ²
		Neem oil	Seed treatment	Six hours before sowing	20% v/w
Check	-	-	-		Untreated infested

2.2 Field preparation:

Experiment was laid out for two consecutive crop seasons during 2015-16 and 2016-17 on same naturally root-knot nematode infested polyhouse at Department of Horticulture, CCS HAU, Hisar, Haryana, India. Root-knot nematode species were identified by using the perineal pattern (Netscher and Taylor, 1974) from naturally infested polyhouse before experimentation. From infected roots, fungus isolation was done on PDA Petri plates. Identification of fungus (*Fusarium oxysporum*) was confirmed (Leslie and Summerell, 2006). Experimental site having sandy loam soil (sand, silt and clay, 85.7, 6.3 and 8.0 per cent respectively) with an organic matter content (11 g kg⁻¹ soil) and pH 6.5.

Treatments application

Fumigation with formalin was done before 20 days of sowing and other chemicals were incorporate at sowing time. Harrowing was done in the field to maintain porosity in the field before application of fumigant. Drenching of formalin was done and mix well in the soil. After application of the fumigant quickly seal the soil with the help of transparent plastic (LLDP) polyethene sheet. Neem cake, neem leaves and bio-agents were applied into soil after fumigation treatment and 15 days before sowing for proper decomposition of the materials. In each plot neem leaves, neem cake and bio-agents were equally applied in the plot and mix well with the help of hand hoe. After mixing of the amendments maintain the moisture level for proper activity. Carbofuran granules directly apply by broadcasting method and well mix in the soil before sowing. Fungicide solution prepared by mixing 2 g bavistin in 1 L water and drench on the soil surface with the help of mug before sowing. Seeds were treated with neem oil six

hour before sowing. Seeds were treated with *Purpureocillium lilacinus* before sowing. After treatment, the seeds were dried in shade for six hours.

2.3 Polyhouse trials:

The integrated management strategies against *Meloidogyne incognita* and fungal pathogen in cucumber under polyhouse for two consecutive seasons. The initial nematode population before incorporation of various treatments was 291 J₂/ 200 cc and 256 J₂/ 200 cc soil during first and second season, respectively. Nematode interacted with spores of soil borne fungus (*F. oxysporum* f. sp. *cucumerinum*) from the earlier cucumber crops. Three seeds of cucumber (cv. Sania) were sown at each place on beds and after germination one plant was maintained. Total of 33 plots (20 × 1 m² each) inside the polyhouse. One bed counted as single replication of the treatment. Total twenty plants with spacing (1 X 1 m) were maintained on each bed. Plants were supported by nylon thread. Each treatment replicated three times and arranged by randomized block design. First season (from April 15th to 19th July, 2016) and second season (from August 25th to December 5th, 2016) had conducted in polyhouse.

During both the seasons, cucumber plants were maintained as per requirement, manage for insect pest. General care and maintenance of plants were done as recommended by CCS Haryana Agricultural University, Hisar (Anonymous 2015). For both seasons cumulative yield of cucumber per replication were recorded. Cucumber fresh roots were kept in the oven for drying after harvesting and then dry root weight was taken. Twelve picking in the first season, and once in September and twice in October and November and thrice in December for the second season.

Table 2
Treatment's detail

T1	Neem cake 200 g/m ² + neem oil seed treatment 20% v/w
T2	Neem cake 200 g/m ² + <i>P. lilacinus</i> seed treatment 20 g/kg seed
T3	Neem leaves 200 g/m ² + neem oil seed treatment 20% v/w
T4	Neem leaves 200 g/m ² + <i>P. lilacinus</i> seed treatment 20 g/kg seed
T5	<i>P. lilacinus</i> soil application 50 g/m ² + neem oil seed treatment 20% v/w
T6	<i>P. lilacinus</i> soil application 50 g/m ² + <i>P. lilacinus</i> seed treatment 20 g/kg seed
T7	Formalin 250 ml/m ² + <i>P. lilacinus</i> seed treatment 20 g/kg seed
T8	Formalin 250 ml/m ² + neem oil seed treatment 20%v/w
T9	Carbofuran 10 g/ m ²
T10	Bavistin 2 g/l water
T11	Control (inoculated)

2.3 Data collection and trial assessments

The nematode population in soil was determined at crop maturity by collecting soil samples with a 2.5-cm diam. soil probe to a depth of 15–20 cm from the rhizosphere of five cucumber plants per plot, then the five cores were

combined to form one composite sample per plot. *Meloidogyne incognita* were extracted from 200 g soil from each sample using a standard Cobb's sieving method (Cobb, 1918) followed by Modified Baermann's technique (Viglierchio and Schmitt, 1983) and counted (Jenkins 1964). The extracted second-stage *M. incognita* juveniles (J_2) were counted under binocular microscope

After crop maturity, observations were taken for shoot length, dry root weight, cumulative yield of cucumber (q/ha). Five randomly nominated plants per plot was measured. Cumulative yield of cucumber was determined by assembling fruit ten times during the season. On each harvest date, marketable cucumber fruits in each plot were picked and weighed. Total cucumber fruit yield for each treatment was documented as the sum of the ten harvest dates at the termination of the experiments.

Fungal incidence of *Fusarium oxysporum* f. sp. *cucumerinum* was recorded from 5 plants per plot at 15 and 30 days after sowing conferring to a 0–5 scale (0 = root healthy; 1 = 1–10% affected root surface (a.r.s.); 2 = 11–25% a.r.s.; 3 = 26–50% a.r.s.; 4 = 51–75% a.r.s. and 5 $\geq$ 76% a.r.s.). Analysis of *F. oxysporum* infection was confirmed by isolation of the fungus. Consequently, symptomatic tissues of cucumber plants (1 mm²) were sterilized, rinsed in sterile distilled water and placed in Petri dishes containing acidified potato dextrose agar medium (PDA), amended with sodium hypochloride (0.1 %) and assessed by using given formula.

$$\text{Disease incidence} = \frac{\text{No. of infected plants} \times 100}{\text{Total no. of plant assessed}}$$

Plates were incubated in BOD at 25 ± 1 ° C temp. The slides were prepared and examined under microscope for confirmation of *Fusarium oxysporum* (Leslie and Summerell, 2006).

Data analysis

Statistical analysis was done by using SPSS software (SPSS for Windows). Means were compared by analysis of variance (ANOVA) and Duncan's test of multiple comparisons ($P < 0.05$). The data compared with means of treatment as significant and non-significant.

Results

3.1 Effects of combine methods on plant growth and yield of cucumber

No phytotoxic effect was not observed in formalin treated plots. During both the seasons, significantly ($P < 0.05$) highest shoot length and dry root weight of cucumber were obtained by application of formalin with neem oil seed treatment as compared to other treatments (Table 3). In the first season (Fig. 1), quantity of cucumber fruit was lesser in the untreated control (22.0 t/ha), while the collective yield significantly ($P < 0.05$) enhanced in the treated plots (70.7 t/ha) (Table 3). In second season, the effects of combine methods on production variables were much more pronounced compared to earlier season. However, analogous trend was found in the second season experiment, cucumber plant height (186.6 cm) treatment was significantly greater than other treatment. No significant differences occurred between formalin with *P. lilacinus* and carbofuran. The average yield was significantly higher (Fig. 2) where management practices were applied formalin and neem oil seed treatment giving the greatest yield (77.3 t/ha) over the untreated check (25.0 t/ha) (Table 3). However, the cumulative fruit yield was significantly $P < 0.05$ higher in all treated plots, including those treated with carbofuran and Bavistin alone.

3.2 Effects of combined methods on nematode reproduction and fungal incidence in cucumber

The data indicated in Table 4, during 2015-16 first season final nematode population (155 J₂ per 200 g soil) and galls per plant were significantly reduced in the plots treated with formalin and seed treatment with neem oil seed treatment over untreated inoculated check. Application of formalin and neem oil seed treatment was most effective in reducing root galling, nematode population and reproduction factor, which was comparable to neem cake and *P. lilacinus* seed treatment. In the 2016-17, second season the final nematode population and galls per plant had declined more as compared with first season. An analogous result was found in the 2016-17 experiment, nematode population 141 J₂ per 200 g soil, galls and reproduction factor was significantly greater than in untreated checks (Table 4). At harvest, there was no difference between number of galls in formalin + neem oil and formalin + neem oil treatment between, but reduced *M. incognita* galls significantly as compared with all other treatments.

The severity of the nematode and soil borne fungus, diseases complex was reduced in treated plots during both the seasons as compared with untreated plots at 15 and 30 days after sowing (Table 5). Fungus incidence and root galling was severe in untreated plots during the first crop season (Table 5). Through the second season of crop, significant reduction in fungal incidence was found in formalin and neem oil seed treatment treated plots as compared to untreated control (Table 5) at 15 and 30 days after sowing. The reduced galling echoed the decrease in fungal disease incidence recorded during the second season of cucumber. Fungus incidence was significantly lowest in both season wherever formalin and neem oil seed treatment were applied followed by neem cake and *P. lilacinus* seed treatment as compared to untreated inoculated check.

Table 3

Effect of integrated management practices on growth and yield of nematode infested cucumber crop in polyhouse conditions

Treatments	First season			Second season		
	Shoot length (cm)	Dry root weight (g)	Yield (t/ha)	Shoot length (cm)	Dry root weight (g)	Yield (t/ha)
T1	176.4 ^{ef}	8.58 ^{bcd}	52.0 ^f	172.7 ^{ef}	9.00 ^{de}	61.3 ^e
T2	180.6 ^{fg}	11.58 ^{cd}	64.7 ⁱ	184.0 ^h	14.33 ^{gh}	74.7 ^{hi}
T3	160.4 ^c	7.52 ^{bc}	37.3 ^c	155.0 ^c	7.00 ^{bc}	60.0 ^{de}
T4	170.2 ^{de}	8.26 ^{bc}	47.7 ^e	167.3 ^{de}	8.30 ^{cd}	56.3 ^{cd}
T5	163.2 ^{cd}	8.11 ^{bc}	42.7 ^d	161.7 ^{cd}	7.67 ^{bcd}	53.0 ^c
T6	176.5 ^{ef}	8.51 ^{bcd}	54.0 ^{fg}	174.7 ^{fg}	10.33 ^{ef}	64.3 ^{ef}
T7	179.6 ^{efg}	9.58 ^{bcd}	56.7 ^{gh}	180.0 ^{gh}	11.00 ^f	67.7 ^{fg}
T8	186.6 ^g	12.58 ^d	70.7 ^j	197.9 ⁱ	15.67 ^h	77.3 ⁱ
T9	177.9 ^{efg}	10.58 ^{bcd}	59.3 ^h	181.7 ^{gh}	13.00 ^g	70.3 ^{gh}
T10						
	128.0 ^b	6.58 ^b	32.7 ^a	132.0 ^b	6.00 ^b	33.3 ^b
T11	107.2 ^a	2.58 ^a	22.0 ^b	107.2 ^a	2.91 ^a	25.0 ^a

Four replications of each treatment arranged in a randomized block design. In each column values with same letters denote non-significant difference ($P < 0.05$) according to Duncan's test of multiple comparisons.

Table 4

Effect of integrated management practices on nematode population in cucumber under polyhouse conditions

Treatments	First season				Second season			
	Egg masses per plant	Galls per plant	Final nematode population	Reproduction factor	Egg masses per plant	Galls per plant	Final nematode population	Reproduction factor
T1	185 ^e	210 ^f	250 ^e	0.8	166 ^f	203 ^e	238 ^e	0.9
T2	95 ^b	112 ^c	217 ^c	0.7	85 ^c	103 ^c	201 ^c	0.8
T3	224 ^g	241 ^h	340 ^h	1.2	217 ^h	230 ^h	328 ^h	1.3
T4	195 ^f	220 ^{fg}	275 ^f	0.9	183 ^g	214 ^f	262 ^f	1.0
T5	215 ^g	230 ^g	315 ^g	1.0	208 ^h	221 ^g	312 ^g	1.2
T6	160 ^d	198 ^e	238 ^d	0.8	145 ^e	181 ^d	233 ^e	0.9
T7	55 ^a	75 ^b	170 ^b	0.5	48 ^b	73 ^b	161 ^b	0.6
T8	48 ^a	60 ^a	155 ^a	0.5	32 ^a	53 ^a	141 ^a	0.5
T9	145 ^c	185 ^d	218 ^c	0.7	126 ^d	180 ^d	214 ^d	0.8
T10	456 ^h	485 ⁱ	718 ⁱ	2.4	446 ⁱ	482 ⁱ	696 ⁱ	2.7
T11	553 ⁱ	570 ^j	890 ^j	3.0	560 ^j	594 ^j	902 ^j	3.5

Nematode multiplication was calculated as a ratio of Final nematode Population/Initial nematode Population. Four replications of each treatment were arranged in a randomized block design. In each column same letter values denote non-significant difference ($P < 0.05$) according to Duncan's test of multiple comparisons.

Table 5
Effect of integrated management practices on damping off (Percent fungal incidence) in
cucumber under polyhouse conditions

Treatments	First season		Second season	
	Pre emergence (15 DAS)	post emergence (30 DAS)	Pre emergence (15 DAS)	post emergence (30 DAS)
T1	13 ^{abc}	20 ^{bc}	27 ^a	33 ^{cd}
T2	7 ^{ab}	7 ^{ab}	20 ^a	14 ^{ab}
T3	20 ^{bc}	20 ^{bcd}	33 ^a	33 ^{cd}
T4	20 ^{abc}	20 ^{bc}	27 ^a	20 ^{bc}
T5	20 ^{bc}	27 ^{bcd}	33 ^a	40 ^{de}
T6	27 ^{bc}	33 ^{cd}	33 ^a	40 ^{de}
T7	13 ^{abc}	13 ^{ab}	27 ^a	20 ^{bc}
T8	1 ^a	1 ^a	14 ^a	1 ^a
T9	27 ^{bc}	33 ^d	33 ^a	53 ^e
T10	33 ^{bc}	40 ^{cd}	33 ^a	40 ^{de}
T11	47 ^c	80 ^e	40 ^a	93 ^f

DAS = Days after sowing, Four replications of each treatment in a randomized block design. In each column same letters values denote non-significant difference ($P < 0.05$) according to Duncan's test of multiple comparisons.

Discussion

Root-knot nematodes and soil borne fungus are main constriction to the production of vegetable crops under polyhouse conditions including cucumber throughout the India, with few effective control methods available (Collange et al. 2011; Jones 2017). Therefore, it is imperative requirement toward discovery actual and economically practicable fumigant nematicides for management of *M. incognita* and soil borne fungus of monetary implication. In this experiment, we demonstrated that integrated use of formalin and seed treatment with neem oil was highly effective against *M. incognita* and soil borne fungus and significantly enhanced cucumber yield. Application of formalin and neem oil seed treatment suppressed nematode population and reproduction rate of *M. incognita* during the both seasons and neem oil was also helpful to enhance the germination percentage and increase microbial activity in to the soil. Combined application of formalin and seed treatment with neem oil suppressed soil borne fungus infection in cucumber during both the seasons. After the formalin treatment soil was quickly covered with polythene sheet (LLDP) this has very helpful to reduce the risk of toxicity. The covered polythene sheet has very helpful to modification in physicochemical and biological properties like, increasing the availability of mineral nutrients and soluble organic matter that affects soil micro flora and soil micro fauna these are agreement with Mola et al. 2021.

Damages caused by the *M. incognita* along with *F. oxysporum* f. sp. *cucumerinum* has adverse effects on production of cucumber in polyhouse, causing significant monetary losses to polyhouse farmers (Koenning et al. 1999; Patil et al. 2017a). Possibly because juveniles of root-knot nematode puncturing the roots, preferred by fungus penetration. Growth of cucumber were significantly better where application of formalin with neem oil seed treatment over untreated control. The achievements also concord with the statements of (Stephan et al. 1998; Meher et al. 2010; Patil et al. 2018c; Kumar et al. 2019) that the who described that fumigants were effective in reducing nematode populations, significantly increased the growth and yield of vegetable crops crop. Based on our findings, integrated management practices i.e., addition of formalin along with seed treatment with neem oil has been reported to enhance produce of cucumber and decline in fungal incidence and significant reduction in nematode populations suggested to farmers for the vegetable production under polyhouse cultivation. These finding are in concur with (Faruk et al. 2011; Collange et al. 2011; Akhtar and Malik 2000; Katan 2017) reported that integrated management could be used to manage *M. incognita* and fungal disease complex in vegetable crops and also enhance yield.

Fumigation and seed treatment with neem oil have been widely used to control soilborne pathogens (Moubark and Abdel-Monaim 2011; Patil et al. 2018c; Radwan et al. 2012; Kumar et al. 2019). Nevertheless, information on the integrated management of both pathogens under polyhouse conditions on cucumber growth and fruit yield are limited in India. The positive consequence of the amendments in enlightening the performance of bio-agent had been showed in this investigation. Neem oil may have enhanced beneficial microbial activity resulted in a significant improvement of soil profile and germination percentage of cucumber seeds.

In polyhouse trials, our findings are also coinciding with Stephan et al. (1998) stated that the organic amendments applied with chemicals reduced nematode reproduction in tomato and eggplant. Complex disease was minimum wherever soil treated with formalin and neem oil seed treatment followed by soil application of formalin with *P. lilacinus*. (Akhtar et al. 2005; Patil 2017c; Mishra et al. 2017;) conclude that integration of formalin with neem oil reduced the *Fusarium* wilt disease severity than individual application of carbofuran and Bavistin. Neem oil and *Purpureocillium lilacinus* has repelling effects on soil borne fungus, when applied to manage the *M. incognita* and *Fusarium oxysporum* f. sp. *lycopersicum* disease complex by Nagesh et al. (2006). The suggested methods might be change in the soil micro flora and fauna, which had suppressive effects on disease (Schlatter, 2017). This integration with neem oil could be executed over the increase in useful soil microorganisms into the soil, thus endorsing the environment eminence leading to suppression of fungus and nematode reproduction (Oka et al. 2007; Oka 2010; Moosavi. 2020).

During the first crop season, yield and growth of the cucumber was less as compared to the second season. The integrated use of fumigants and seed treatment with neem oil used in this investigation ensured suppressive effects on nematode population and fungus. Though, the use of formalin and organic oil enhanced the cucumber yield over control, although the crop was infected by root-knot nematode and soil borne fungus. These two integrated management strategies have been taken into deliberations by the polyhouse growers for cucumber or vegetables.

Declarations

Author contributions The trial was planned, executed and the document written by JAP. SJ, AK and SR took care of maintenance of the experiment.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Informed consent All co-authors have given consent to the publication of this manuscript.

Ethical approval The study did not involve human participants or animals.

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Figures

Figure 1

Total cucumber yield (t/ha) in polyhouse after treatments. (during first season)

Figure 2

Total cucumber yield (t/ha) in polyhouse after treatments. (during second season)