ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2026): 4.97
IJAFS 2026; 8(4): 413-417
www.agriculturaljournals.com
Received: 10-03-2026
Accepted: 11-04-2026

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Management of root-knot nematode, *Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949 in ginger

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DOI: https://www.doi.org/10.33545/2664844X.2026.v8.i5e.1537

Abstract
The investigation titled "Management of root-knot nematode, *Meloidogyne incognita* (Kofoid & White, 1919) Chitwood, 1949 in ginger" was carried out under the All India Coordinated Research Project on Nematodes in Agriculture at Mahatma Phule Krishi Vidyapeeth, Rahuri during 2024-2025 with objective to manage root-knot nematode using bioagents under field condition. A field experiment on ginger *cv. Mahima* compared seven treatments. all treatments significantly reduced nematode populations and damage compared to the control, but the most effective and economically feasible integrated treatment was in-situ sunhemp mulching @2kg/m² combined with *P. chlamydosporia* enriched FYM @100 g/m² applied at planting and repeated at 3 MAP, which recorded the highest reductions in nematode population (39.72% at 3 MAP and 28.76% at harvest), the lowest egg masses (4.33/5 g roots) and root galls (14.67/5 g roots) at termination and the highest yield (19.52 t/ha). soil solarization + *P. chlamydosporia* enriched FYM @100g/m² at the time of planting and 3 MAP also performed well, whereas fluopyram 34.48 % SC provided rapid short-term suppression and the highest ICBR (1:17.09) but is less desirable from a sustainability standpoint.

Keywords: Ginger, *Meloidogyne incognita*, Absolute frequency, Average population, Prominence value, *P. chlamydosporia*, Sunhemp, Fluopyram 34.48 % SC, Root galls, Egg masse

Introduction

Ginger (*Zingiber officinale* Rosc.), belonging to Zingiberaceae family was first described in the book, *Hortus Indicus Malabricus* in 1692 by Rheede. Its origins are generally attributed to India or China, with references appearing as early as 500 BCE in the writings of the philosopher Confucius. It is highly valued for rhizome known for its significant nutritional and medicinal benefits. Ginger contains essential nutrients such as carbohydrates, dietary fibre, protein and trace amounts of vitamins and minerals including vitamin C, vitamin B6, magnesium, potassium and iron, making it a nutrient-dense food (Bhati and Raghuvanshi, 2021) [1]. It is a major spice with significant production and marketing value in global trade. India has been a large producer of ginger for many years, with the production of 22 lakh tons of fresh ginger cultivated in an area of 1.9 lakh hectares during the year 2024–25 (Spices Board of India, 2025). Among the major biotic constraints of ginger, diseases play an important role. Ginger is severely affected by soil-borne diseases *viz.* soft rot, bacterial rot, fusarium yellows and nematode-disease complex including *Meloidogyne* spp., *Radopholus similis* and *Pratylenchus* spp. Root-knot nematodes (*Meloidogyne* spp.) also facilitate secondary infections by different pathogens like *Pythium* spp., *Fusarium* spp. and *Ralstonia* spp. (Udo and Ugwuke, 2010) [17]. Though several plant-parasitic nematodes have been recorded from ginger, the most important nematode pests are root-knot and burrowing nematodes (Guo *et al*., 2004; Kaur *et al*., 1989; Luqman *et al*., 1998; Routaray *et al*., 1987; Sheela *et al*., 1995; Vadhera *et al*., 1998) [5, 6, 8, 13, 15, 18]. Root-knot nematodes (*Meloidogyne* spp.) infest several agricultural and horticultural crops all around the world. In India the annual losses due to root knot nematode are around 29 - 30 per cent (Kumar, *et al*., 2020). Various species of *Meloidogyne* attack nearly every crop sown, where not only are yields greatly affected but quality is also compromised (Sasser, 1980) [14]. In this context the study was conducted to evaluate the efficacy of different bioagents for the nematode management.

Methodology
Nematode population isolation and identification
The soil samples were processed by Cobb's decanting (Cobb, 1918) [2] and sieving method and Modified Baermann's funnel technique. First, the soil from the polythene bag was spread on the table, mixed well. Then about 200cc of soil sample was taken into plastic pan, one litre of water was added and stirred well in order to prepare a soil suspension. The suspension was allowed to stand for about 10 seconds so that sand and heavier particles settled down. The muddy soil suspension was passed through an assembly of phosphoro-bronze wire-netted sieves of 20, 60, 200 and 350 mesh sieves. Contents of 200 and 350 mesh sieve were collected into a 200cc beaker by backwashing the sieve with gentle stream of water from the tap. Each soil sample was wet screened in the same manner to collect most of the nematodes. The whole suspension collected in the beaker was poured onto a double layer tissue paper resting on a supporting wire-gauge matching the petri dish. The wire gauge assembly was then placed on petri dish containing sufficient water such that the bottom of the wire gauge tissue paper assembly was slightly submerged in water. The assembly was covered by lid to prevent loss of water due to evaporation and left as such for 24 hours, so as to allow maximum number of nematodes to wriggle out through the tissue paper into the bottom of petri dish. Next day 1 ml suspension was taken out with the help of micro pipette in counting dish, put on the stage of the stereoscopic microscope to examine the presence of nematodes. In this manner all samples screened were processed following modified Baermann's Funnel Technique to get clear nematode suspension.

$$\text{Population Density} = \frac{\text{Number of Nematodes}}{\text{Total Number of Samples}}$$

$$\text{\% of Nematode occurrence} = \frac{\text{Number of positive samples}}{\text{Total number of samples}}$$

Nematode population assessment
The 200 g of composite soil samples were collected from each treatment at the time of observation. The residues of 200 and 350 mesh sieves were collected in plastic beaker and the volume of beaker was adjusted to 200 ml by adding tap water. The nematode count, the average of 10 counts of 1 ml suspension was recorded and from this it was calculated to 200 ml of solution. From these observations, per cent decrease in nematode population was worked out. For roots, these were stained with 0.1 per cent boiling acid fuchsin lactophenol for 1 minute and washed in tap water to remove excess stain and then kept in pure lactophenol for overnight for destaining (McBeth *et al*, 1941) [9]. The roots were then examined under the stereoscopic binocular microscope for number of root galls and egg masses per 5 g of roots. On the basis of these observations, per cent decrease in root galls and egg masses were worked out. Incidence of root-knot nematode was recorded by using the gall index (Gaur *et al*., 2001) [4] which is as follows.

Root knot index scale	Number of galls
1	0
2	1-10
3	11-30
4	31-100
5	>100

Treatments details

Tr. No.	Treatments	Dose/ha
T_1	Soil solarization using 25 µm transparent polythene for two weeks before planting.	240 kg
T_2	T_1 + Neem cake (100gm/m^2) at the time of planting and 3MAP	240 kg + 2 tonnes
T_3	T_1 + *P. chlamydosporia* enriched FYM @100gm/m^2 at the time of planting and 3MAP at the time of planting	240 kg + 2 tonne
T_4	In-situ mulching of sunhemp (2kg/m^2) + *P. chamydosporia* enriched FYM @100gm/m^2 at the time of planting.	20 tonnes + 1 tonnes
T_5	In-situ mulching of sunhemp (2kg/ m^2) + *P. chlamydosporia* enriched FYM@100gm/m^2 at the time of planting and 3MAP.	20 tonnes + 2 tonnes
T_6	Fluopyram 34.48% SC (vellam prime) at the time of planting	625 ml

Result and Discussion
1. Effect of various treatments on root-knot nematode population (J_2) / 200 cc of soil
The initial nematode population across all the applied treatments ranged from 440 to 486.67 J_2 per 200 cc of soil. It was observed from data depicted in Table no. 2 that all the treatments applied were greatly superior over an untreated control in reducing the root-knot nematode population at intermediate and termination stage of the experiment. The most effective treatment at this stage was T_5, which involved in-situ mulching of sunhemp @2kg/m^2 combined with *P. chlamydosporia* enriched FYM @100 g/m^2 applied both at planting and again at 3 months after planting. This treatment recorded a 39.72 per cent decline in nematode population. T_3, which combined soil solarization with *P. chlamydosporia* enriched FYM @100 g/m^2, and T_6, which used Fluopyram (34.48 % SC) also showed good performance with 37.50 per cent and 37.87 per cent reductions, respectively. T_2, which added neem cake @100 g/m^2 to soil solarization, followed closely with a 36.23 per cent decline. T_1 and T_4 were moderately effective, while the untreated control (T_7) showed no reduction.

At 6 months after planting, the trend of effectiveness remained consistent. T_5 recorded a 32.87 per cent reduction in nematode population, followed by T_3 (30.55 per cent) and T_2 (28.98 per cent). These treatments maintained their superiority over others, indicating sustained efficacy. T_6 showed a moderate decline of 22.72 per cent, while T_1 and T_4 recorded lower reductions of nematode population of 19.70 per cent and 20.58 per cent, respectively. At the time of harvest, T_5 remained the most effective treatment, achieving a 28.76 per cent reduction in nematode population which was at par with T_3 and T_2 with 26.38 per cent and 24.20 per cent reductions in nematode population, respectively. The treatment T_6 (Fluopyram 34.48 % SC) though initially effective, showed a slightly lower reduction of nematode population (17.42 per cent) at harvest. The treatment T_4 and T_1 recorded 13.16 per cent and 12.12 per cent decline in nematode population, respectively, indicating a decline in their long-term effectiveness. The untreated control (T_7) continued to show no reduction. Thee combining organic amendments such as sunhemp mulching and bioagent, *P. chlamydosporia*, were found to be more effective in managing root-knot nematode populations. Treatments that included repeated applications or combinations of methods consistently outperformed single interventions, both in the short and long term.

Table 1: Effect of various treatments on the population of Root-knot nematodes (J_2)/200cc soil

Tr. No.	Treatment details	INP***	Intermediate Nematode Population		At harvest	Per cent decline in nematode population		
			3 MAP**	6 MAP		3 MAP	6 MAP	At harvest
T_1	Soil solarization using a 25µm transparent polythene sheet for two weeks before planting	440.00	293.33	353.33	386.67	33.33 (35.26) *	19.70 (26.35)	12.12 (20.37)
T_2	T_1+ Neem cake (100g/m^2) at the time of planting and 3 MAP*	460.00	293.33	326.67	348.67	36.23 (37.01)	28.98 (32.57)	24.20 (29.47)
T_3	T_1 + *P. chlamydosporia* enriched FYM @ 100g/m^2 at the time of planting and 3MAP	480.00	300.00	333.33	353.33	37.50 (37.76)	30.55 (33.55)	26.38 (30.90)
T_4	In-situ mulching of sunhemp (2kg/m^2) + *P. chlamydosporia* enriched FYM (100g/m^2) at palnting	453.33	320.00	366.67	393.67	29.41 (32.84)	20.58 (26.98)	13.16 (21.27)
T_5	In-situ mulching of sunhemp (2kg/m^2) + *P. chlamydosporia* enriched FYM (100g/m^2) at planting and 3 MAP	486.67	293.33	326.67	346.67	39.72 (39.07)	32.87 (34.98)	28.76 (32.43)
T_6	Fluopyram 34.48% SC at the time of planting	440.00	273.33	340.00	363.33	37.87 (37.98)	22.72 (28.47)	17.42 (24.67)
T_7	Untreated control	460.00	486.67	493.33	526.67	-	-	-
	S.E.m (±)	45.43	14.55	10.39	10.06	1.08	1.42	1.44
	CD at 5%	NS	44.83	32.02	30.17	3.33	4.38	4.45
	CV (%)	5.80	7.80	4.96	5.40	5.95	9.51	10.47

2. Effect of various treatments on root galls, egg mass per 5 g root and Root-knot Index

The most effective treatment was T_5 (in-situ mulching of sunhemp at 2kg/m² combined with *Pochonia chlamydosporia* enriched FYM 100g/m² at planting and 3 MAP), which recorded the lowest nematode infestation levels. This treatment recorded 4.33 egg mass per 5 g roots, 14.67 root galls per 5 g roots, with a root knot index as 3.00, indicating strong suppression of root-knot nematode activity. At par with T_5, the T_3 (soil solarization using a 25µm transparent polythene sheet for two weeks before planting + *P. chlamydosporia* enriched FYM at planting and 3 MAP) showed excellent results, reducing egg mass to 6.33 and galls to 16.33 per 5 g roots and the root knot index to 3.00. Moderate suppression was observed in T_2 (soil solarization + neem cake @2kg/m² application), which reduced egg mass to 10.33 and galls to 24.33, with a root knot index of 3.00. T_6 (Fluopyram 34.48% SC at planting) also lowered nematode populations (16.00 egg mass, 25.33 galls, root knot index 4.00), but its efficacy was comparatively less than the integrated organic-biological treatments. T_1 (soil solarization) and T_4 (in-situ mulching of sunhemp + *P. chlamydosporia* enriched FYM at planting) provided partial control, recording higher egg mass counts, 26.67 and 24.67 respectively and root knot indices of 4.00 In contrast, the untreated control (T_7) showed the highest nematode reproduction and damage, with 39.67 egg mass, 58.33 root galls, and a root knot index of 4.00, confirming severe infestation under natural conditions. The integrated approaches outperformed chemical nematicides and single-component treatments, highlighting the importance of biological and cultural practices in reducing nematode reproduction, minimizing root damage, and improving crop health. The results of this study have similarities with the findings of Ravindra *et al.* (2014) [11] who reported that application of *Pochonia chlamydosporia* along with *P. lilacinus* showed significant results in reducing population of the root-knot nematodes. Similar findings were also given by Niranjana *et al.*, (2018) [10] who showed that application of bioagents like neem cake in combination with *Pacaelonyces lilacinus* performed better in managing the *Meloidogyne* spp. population in Turmeric. The findings recorded in this study are also on similar lines with Eapen *et al.* (2008) [3] whose final results showed that *Pochonia chlamydosporia* greatly suppressed root-knot nematodes.

Table 2: Effect of various treatment on Egg mass, Root galls and Root knot Index

Tr. No.	Treatment details	Reproduction factor	Number of egg mass/5 g roots	Number of root galls/5 g roots	Root knot index
T_1	Soil solarization using a 25µm transparent polythene sheet for two weeks before planting	1.14	26.67 (5.21)*	55.33 (7.47)*	4.00 (55.33)**
T_2	T_1+ Neem cake (100g/m^2) at planting and 3 MAP	1.33	10.33 (3.29)	24.33 (4.98)	3.00 (24.33)
T_3	T_1 + *P. chlamydosporia* enriched FYM @ 100g/m^2 at planting and 3MAP	1.36	6.33 (2.61)	16.33 (4.10)	3.00 (16.33)
T_4	In-situ mulching of sunhemp (2kg/ m^2) + *P. chlamydosporia* enriched FYM (100g/m^2)	1.24	24.67 (5.02)	38.67 (6.26)	4.00 (38.67)
T_5	In-situ mulching of sunhemp (2kg/m^2) + *P. chlamydosporia* enriched FYM (100g/m^2) at planting and 3 MAP	1.41	4.33 (2.20)	14.67 (3.90)	3.00 (14.67)
T_6	Fluopyram 34.48% SC at planting	1.30	16.00 (4.06)	25.33 (5.08)	3.00 (25.33)
T_7	Untreated	0.87	39.67 (6.34)	58.33 (7.67)	4.00 (58.33)
	S.E.m (±)	0.03	0.36	0.34	-
	CD at 5%	0.11	1.12	1.10	-
	CV (%)	4.9	11.1	8.9	-

Effect of various treatments on yield of ginger and their incremental cost benefit ratio: Analysis of the yield data revealed that all the treatments exerted a significant, resulting in an increase in ginger yield. Among the different treatments, In-situ mulching of sunhemp ($2kg/m^2$) + *P. chlamydosporia* enriched FYM ($100g/m^2$) at planting and 3 months after planting was found to be superior in recording highest yield of ginger 19.52 ton/ha as against 11.70 ton/ ha in untreated control and recorded 1:8.77 ICBR in this treatment. But one time application of fluopyram 34.48% SC at the time of planting recorded highest ICBR of 1:17.09 becoming more cost effective.

Table 3: Effect of various treatments on the yield of ginger and their incremental cost benefit ratio

Tr. No.	Treatment	Yield (t/ha)	Additional yield over control (t/ha)	Cost of Treatment (Rs/ha)	Cost of Labour (Rs/ha)	Plant protection cost (Rs/ha)	Additional profit (Rs/ha)	Net profit (Rs/ha)	ICBR (Rs/ha)
T_1	Soil solarization using a 25µm transparent polythene sheet for two weeks before planting	13.70	2.00	40950	1000	41950	66000	24050	1:0.57
T_2	T_1+ Neem cake ($100g/m^2$) at planting and 3 MAP*	17.47	5.77	120000	2000	122000	190410	67910	1: 0.55
T_3	T_1+ *P. chlamydosporia* enriched FYM @ $100g/m^2$ of planting and 3MAP	18.14	6.44	56950	2000	58950	212520	153570	1:2.60
T_4	In-situ mulching of sunhemp (2kg/ m^2) + *P. chlamydosporia* enriched FYM (100g/ m^2) at palnting	14.47	2.77	16100	1500	17600	91410	40810	1:5.19
T_5	In-situ mulching of sunhemp (2kg/ m^2) + *P. chlamydosporia* enriched FYM (100g/ m^2) at planting and 3 MAP	19.52	7.82	24100	2000	26100	258060	231960	1:8.77
T_6	Fluopyram 34.48% SC at planting	15.50	3.80	6374	500	6874	125400	117526	1:17.09
T_7	Untreated control	11.70	-	-	-	-	-	-	-

Conclusion

At the termination of experiment, treatments of in-situ mulching @$2kg/m^2$ + *P. chlamydosporia* enriched FYM @$100g/m^2$, was found highly useful and potent in reducing population of the root-knot nematode, *Meloidogyne incognita* by 28.57 per cent and 4.33 root galls per 5g roots and 14.67 egg masses per 5g of roots, respectively. This was at par with T_3 (soil solarization using a 25µm transparent polythene sheet for two weeks before planting + *P. chlamydosporia* enriched FYM at planting and 3 MAP) reducing egg mass to 6.33 and galls to 16.33 per 5 g roots and the root knot index to 3.00 and T_2 (soil solarization + neem cake @$2kg/m^2$ application), which reduced egg mass to 10.33 and galls to 24.33, with a root knot index of 3.00. T_6 (Fluopyram 34.48% SC at planting) which also lowered nematode populations (16.00 egg mass, 25.33 galls, root knot index 4.00).

Acknowledgement

The author gratefully acknowledges the Head, department of Entomology and Office in charge, AICRP, on Nematodes in Agriculture, Department of Entomology, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, for extending the necessary facilities and constant support throughout the course of experimentation

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