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RESEARCH

Eco-Friendly Management of Root Knot Nematode (*Meloidogyne* spp.) in Okra (*Abelmoschus Esculentus*) Using Different Soil Amendments

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Abstract

Field experiment was conducted from March to July 2022 to identify the eco-friendly management of root-knot nematodes (*Meloidogyne* spp.) in okra (*Abelmoschus esculentus*) by using different soil amendments. The experiment was designed as a randomized complete block design with three replications and seven treatments viz., mustard oil cake at 1.41 kg/2m^2 plot, poultry manure at 5.6 kg/2m^2 plot, goat manure at 3.25 kg/2m^2 plot, vermicompost at 4.30 kg/2m^2 plot, nitrogen-phosphorus-potassium (NPK) at 125:110:110 g/2m^2, Cartap hydrochloride 4% granule (GR) at 10 g/2m^2 plot and control. Disease parameters such as root gall index and number of galls per plant, fresh shoot weight, and fresh root weight were recorded at 72, 105, and 120 days after sowing. Fruit yield was recorded after the final pod harvest. Cartap hydrochloride 4G, poultry manure, and mustard oil cake significantly reduced the root gall index as compared to the control. However, goat manure, vermicompost nitrogen, phosphorus, and potassium (NPK) did not give satisfactory results in reducing root gall index. The maximum yield of okra was recorded in the NPK treated plots although the root gall index was not much reduced. The research results indicated that the most effective treatment for reducing root-knot nematode disease and improving vegetative growth and yield of okra was poultry manure. Therefore, poultry manure along with mustard oil cake could be used as an alternative to highly hazardous and persistent chemical nematicides for the management of root-knot nematodes in okra.

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Statement of Sustainability: The study on the environmentally friendly management of root-knot nematodes in okra through the use of different soil amendments, with a focus on poultry manure as the most effective option, is directly aligned with Sustainable Development Goal 15: Life on Land. SDG 15 aims to protect, restore, and promote the sustainable use of terrestrial ecosystems, including combating desertification, halting biodiversity loss, and addressing soil degradation. By reducing the need for synthetic chemical nematicides, this environmentally friendly approach promotes sustainable agriculture and food security (SDG 2) by ensuring the availability of safe and nutritious okra crops. This research underscores the importance of responsible agricultural practices in achieving global sustainability goals.

1. Introduction

Okra (*Abelmoschus esculentus* L. Moench; $2n = 2x = 130$) is an important vegetable crop grown mainly in tropical and subtropical regions (Pandey et al., 2019). It is a well-known and widely grown summer vegetable in the lower hills, inner Terai, and Terai regions of Nepal (Acharya and Shakya, 2004). Okra is grown throughout Nepal, with major production areas including Makwanpur (22.4 mt/ha), Lalitpur (20 mt/ha), Kavre (15.6 mt/ha), Surkhet (15.7 mt/ha), and Bardiya (15 mt/ha) (MoALD, 2022). Young and immature okra pods are a versatile ingredient and are best enjoyed when fresh (Ndunguru and Rajabu, 2004). Among these pods, those that are only seven days old have the highest nutritional content and are also used to make pickles (Gemede et al., 2015).

Amatya and Shrestha first observed the presence of root-knot nematodes (*Meloidogyne* spp.) in Nepal in 1969, affecting crops such as tomato, eggplant, okra, and chili. These nematodes are known to infest more than 2000 plant species (Kafle, 2013). Root-knot nematodes are important pests that can cause yield losses of up to 22% in okra (Hussain et al., 2012). Okra production is significantly hampered by various types of insect pests, non-insect pests, and diseases. Among these, root-knot nematodes (*Meloidogyne* spp.) are of paramount economic importance (Mukhtar et al., 2014). In okra, root-knot nematodes cause gall formation and severe growth reduction (Mukhtar et al., 2014). Sikora and Fernández (2005) reported a significant outbreak of root-knot disease in okra caused by Meloidogyne spp. resulting in yield losses of up to 27%.

Strategies used to manage root-knot nematodes in tropical regions include nematicides, crop rotation, soil solarization, flooding, biological control, and soil amendments such as the application of manure, plant material, compost, and wood ash (Manneh, 2016). Alternative methods, such as organic amendments, have also shown some success (Krueger and McSorley, 2008). The link between soil fertility and plant health is strong, influencing a plant's ability to resist pests and diseases. Organic amendments play an important role in improving soil structure and serve multiple soil functions, including carbon cycling, pH regulation, and nutrient retention. They also promote soil biological activity and help control several plant pathogens, including root-knot nematodes (Nagaraju et al., 2010). Numerous studies have demonstrated the effectiveness of these products in managing root-knot nematodes (Oka, 2010). Various types of organic amendments, such as plant materials, animal manures, and composted materials, have been applied to soils to suppress root-knot nematode populations and improve overall crop health and yield (Chang et al., 2007).

Certain organic amendments, particularly those containing chitin, can release ammonia into the soil, directly suppressing plant-parasitic nematode populations and promoting the growth of nematode-fighting microbes. For example, the application of neem seed cake to soil significantly reduced both damage (59.5%) and the population of plant-parasitic nematodes (88.6%) in the soil and on cabbage roots (Zasada et al., 2003). Crucifer decomposition materials have shown promise in controlling root-knot nematodes and other soil-borne plant pathogens (Oka et al., 2007). Oka (2010) explained that tannins and phenolic compounds released during the decomposition of plant residues act as active ingredients that target and kill nematodes. Similarly, Thoden et al. (2011) reported that many plant residues and other amendments release nitrogen compounds and organic acids that are detrimental to nematodes. Ammonia, a common by-product of the decomposition of organic amendments, has been studied extensively. Concentrations of ammonia measured from compost in pot experiments were found to exceed the lethal threshold required to suppress *M. javanica* (Treub) (Oka et al., 2007).

Chemical nematicides such as 1,2-dibromo-3-chloropropane (DBCP) and methyl bromide have been effective in controlling these nematodes, but their high cost, toxicity, persistence in soil, and harm to beneficial soil microorganisms have led to their phasing out (Giannakou et al., 2002). As a result, the use of these chemical nematicides is declining, and some countries have banned them. A more desirable approach to reducing root-knot nematode damage is the development and use of resistant okra cultivars that pose no risk to growers or the environment (Silva et al., 2008). Few suitable resistant genotypes exist for different regions. Although crop rotation is an effective method of nematode control, it is not always adopted by farmers who can't afford to leave fields fallow for long periods. Therefore, there is an urgent need for environmentally friendly, cost-effective, and less toxic alternatives to chemical nematicides in the management of root-knot nematodes (*Meloidogyne* spp.). Thus, this article seeks to determine the effects of different soil amendments on the population of root-knot nematodes (Meloidogyne spp.) over a period of time, along with the effect on the yield of okra with the management of root-knot nematodes.

2. Material and Methods

2.1. Description of the Experimental Site

The study was conducted in the research field of Nepal Polytechnic Institute (NPI) located at Bharatpur-11, Bhojad, Chitwan from April to July 2022. The coordinates of the site are 27°41' 37.21" N latitude and 84°26' 56.29" E longitude with an altitude of 703 feet above sea level. This site was located in the inner Terai region, which is characterized by a subtropical climate. Soil analysis was conducted at the Soil Laboratory of Nepal Polytechnic Institute, Bharatpur, Chitwan. The soil had a moderately acidic pH of 6.3, which was suitable for crop production.

2.2. Experimental Details and Treatment Design

The experiment followed a randomized complete block design (RCBD) with seven treatments and three replications. The total experimental area was 70 square meters (10 m by 7 m), with 0.5 m between each replication and plot. Individual plot dimensions were 1 m by 2 m. Rows were spaced 40 cm apart, and plants within each row were spaced 20 cm apart. Each plot contained 5 rows of 5 plants each, for a total of 25 plants in each plot. Data required for the experiment were recorded from a random selection of the inner 10 plants within each plot. There were a total of seven treatments, including an untreated control, with details of commonly available soil amendments (treatments) as shown in Table 1.

Table 1. Treatments details used in this experiment.

Treatment	Soil Amendments	Quantity/Plot
T1	Mustard oil cake	1.41 kg/2m^2
T2	Poultry Manure	5.6 kg/2m^2
T3	Goat Manure	3.25 kg/2m^2
T4	Vermicompost	4.30 kg/2m^2
T5	NPK	125:110:110 g/2m^2
T6	Cartap Hydrochloride 4% GR	10 g/2m^2
T7	Control	-

GR: Granules; NPK: nitrogen, phosphorus, and potassium.

2.3. Field Preparation and Cultural Practices

The experimental field was prepared by deep plowing and disking two days before sowing. The whole field was thoroughly weeded. The field was divided into 21 experimental units to accommodate seven treatments, each with three replications. One day before sowing, organic amendments including mustard oil cake, poultry manure, goat manure, and vermicompost were spread on the plots. They were then carefully mixed into the soil to a depth of 10 centimeters using a hand fork and covered with soil to promote decomposition and even distribution in the soil. Cartap hydrochloride (4% GR) and NPK were applied two hours before planting. Untreated seeds of the popular okra variety known as Arka Anamika were collected as it is commonly grown and preferred by vegetable farmers in Nepal. The seeds were soaked in water overnight. Two to three seeds were then sown per mound to ensure germination and achieve the desired plant population. Seeding was done with a row-to-row spacing of 40 centimeters and a plant-to-plant spacing of 20 centimeters. To maintain one seedling per mound, excess seedlings were thinned out 15 days after germination. Weeding was performed with a hoe at 15, 30, 40, 50, 70, 90, and 110 days after sowing (DAS). Supplemental irrigation was applied as needed when plants showed signs of water deficiency.

2.4. Data Collection

Data were collected from both the plants and their roots. Initially, ten of the twenty-five plants in each plot were randomly selected and marked for data collection. Before any treatments were applied, we systematically collected five core-soil samples from the experimental field at a depth of 0-15 cm using a soil auger. These samples were transported to the laboratory for evaluation of the root-knot nematode population. Soil nematodes were extracted using the modified Baermann-Tray method. The assessment indicated that the field was infested with root-knot nematodes and their population exceeded the Ethylene Response Pathway (ERP). To measure plant development, plant height was measured from the base of the stem to the top of the tallest branch using a tape measure. Similarly, root length was measured from the base of the stem to the tip of the longest root at 72, 105, and 120 DAS using a tape measure. The plant shoot was separated from the base of the stem (collar) and weighed immediately after harvest using an electronic balance. Roots were also removed from the base of the stem (collar), cleaned in water, and weighed individually using an electronic balance to determine the fresh root weight for each plant.

2.4.1. Gall Index

At 72, 105, and 120 DAS, we carefully uprooted three plants from each plot, taking care not to miss even the root hairs. The uprooted okra plants were then thoroughly washed to clean the roots, and we recorded both the number of galls per plant and the size of each gall. The level of nematode infestation on the plants was scored on a scale of 0 to 5 according to Taylor and Sasser (1978):

Where, 0 = no galls or egg masses; 1 = 1-2 galls or egg masses; 2 = 3-10 galls or egg masses; 3 = 11-30 galls or egg masses; 4 = 31-100 galls or egg masses, and 5 = > 100 galls or egg masses per root system.

Similarly, Bridge and Page (1980) rated nematode infestation on plants on a 0-10 scale:

Where, 0 = No knot on roots; 1 = Few small knots, difficult to find; 2 = small knots only but clearly visible, main roots clean; 3 = some larger knots visible, main roots clean; 4 = larger knots predominate but main roots clean; 5 =50% of roots infested, knotting on some main roots, reduced root system; 6 = visible knotting on main roots; 7 = majority of main roots knotted; 8 = all main roots are knotted; 9 = all roots severely knotted, the plant usually dying, and 10 = all roots severely knotted, no root system, the plant usually dead.

2.4.2. Fruit Yield

The weight of okra fruits collected from each plant was measured to assess yield. The first harvest took place 49 DAS and the fruits were selected when they were still tender. Throughout the study, harvesting was done in 16 different rounds. Fruit yield data at different intervals were combined to determine the final results for each treatment.

2.5. Statistical Analysis

The collected data were tabulated and processed in Microsoft Excel (Microsoft Corp., USA). The recorded data on different parameters were analyzed using GenStat software (VSN International, UK), and the means were separated using Duncan's Multiple Range Test (DMRT).

3. Results and Discussion

3.1. Effects on Fresh Root Weight of Okra

The average fresh root weight per okra plant (measured in g) under different treatments in the field yielded different results. At 72 DAS, the highest fresh root weight per plant (58.89 g) was recorded in the plots treated with vermicompost, followed by goat manure (56.33 g), poultry manure (46.00 g) and other treatments as shown in Figure S1. Conversely, the lowest root weight per plant (33.44 g) was observed in the Cartap hydrochloride-treated plots. At 105 DAS, the poultry manure-treated plots had the highest root weight per plant (109.33 g), followed by NPK (103.89 g) and goat manure (99.22 g). The lowest root weight per plant (42.56 g) was found in the plots treated with Cartap hydrochloride 4% GR, which was comparable to the control and untreated plots. At 120 DAS, the poultry manure-treated plots had the highest root weight per plant (96.78 g), followed by NPK (82.56 g) and goat manure (79.11 g). In contrast, the lowest root weight per plant (41.33 g) was observed in the plots treated with Cartap hydrochloride. The effect of different treatments on fresh root weight per plant varied, with poultry manure consistently resulting in higher root weights in okra plants compared to the other treatments at 72, 105, and 120 DAS. The present results are also consistent with those of other researchers. Among the organic amendments, poultry manure was considered to be the best amendment for controlling nematode population and gall formation, and thus promoting root growth (Faruk et al., 2012). Bari et al. (1999) reported that soil amendment with poultry manure was effective against root-knot nematodes on okra. Similar results were reported by Bari et al. (2004) on brinjal and Hassan et al. (2010) on tomato.

3.2. Effects on Fresh Shoot Weight of Okra

The average fresh shoot weight per okra plant under different treatments in the field is presented in Table 2. At 72 DAS, the plots treated with vermicompost had the highest fresh shoot weight per plant (527.1 g), followed by goat manure (509.1 g) and NPK (469.9 g). Conversely, the lowest fresh shoot weight per plant (283.8 g) was observed in the plots treated with Cartap hydrochloride at 4% GR. At 105 DAS, the highest fresh shoot weight per plant (696.00 g) was recorded in the NPK-treated plots, followed by poultry manure (647.2 g) and goat manure (543.3 g). The lowest fresh shoot weight per plant (236.3 g) was observed in the Cartap hydrochloride 4% GR treated plots, which was similar to the control and untreated plots (287.8 g). At 120 DAS, poultry manure-treated plots had the highest shoot weight per plant (702.9 g), followed by mustard oil cake (522.2 g) and NPK (504.7 g). The lowest shoot weight per plant (182.8 g) was found in the control plots, followed by the plots treated with Cartap hydrochloride 4% GR (296.6 g). Notably, there were no significant differences in shoot weight per plant between the mustard oil cake and goat dung-treated plots. It's important to note that okra plants grown in soil amended with organic matter had significantly higher shoot weights than their unamended counterparts (Faruk et al., 2012). Among the various organic amendments, poultry manure was found to be the most effective in controlling nematode populations and gall formation, thereby promoting robust vegetative growth (Renčo and Kováčik, 2012) and shoot weights (Faruk, 2019; Faruk et al., 2018).

Table 2. Effect of soil amendments on fresh shoot weight/plant (g) of okra plant.

Treatments	Shoot Weight (g)		
	72 DAS	105 DAS	120 DAS
Mustard oil cake	411.2±55.17	503.1±156.56^{ab}	524.2±72.95^{ab}
Poultry manure	452.9±98.19	647.2±144.44^{ab}	702.9±112.34^{a}
Goat manure	509.1±32.95	543.3±205.67^{ab}	432.2±181.22^{abc}
Vermicompost	527.1±182.56	272.0±60.36^{ab}	255.1±75.05^{bc}
NPK	460.9±65.79	696.0±21.41^{a}	504.7±58.35^{ab}
Cartap hydrochloride 4% GR	283.8±29.78	236.3±31.92^{b}	296.6±47.90^{ab}
Control	340.1±87.04	287.8±153.29^{ab}	182.8±11.94^{c}
$LSD_{0.05}$	Ns	394.3	293.8
CV (%)	31.2	48.7	39.9
f-value	1.33	2.18	3.61

Means within the column followed by the same letter are not significantly different at a 5% level of significance by DMRT. SEM = Standard Error of Mean, LSD= Least Significant Difference, and CV = Coefficient of Variation. Ns = non-significant.

3.3. Effects on Number of Galls Per Plant of Okra

The number of galls per plant evaluated under different treatments at 72, 105, and 120 DAS showed significant differences ($p < 0.05$) as shown in Table 3. At 72 DAS, the application of Cartap hydrochloride at 4% GR resulted in the absence of root galling. The root galling index (RGI) was lowest in the plots treated with Cartap hydrochloride at 4% GR, followed by those treated with poultry manure and mustard oilseed cake. The highest number of galls per plant (2.77) was observed in the control plots, followed by the NPK-treated plots. Similarly, at 105 DAS, root galling was significantly reduced ($p < 0.05$) in plots treated with Cartap hydrochloride 4% GR (0.33), followed by poultry manure (0.55) and mustard oilseed cake (2.22). The highest galls per plant (4.55) were recorded in the control plots, followed by the NPK-treated plots. No significant difference in RGI was observed in the goat manure (2.88) and vermicompost (2.66) treated plots. At 120 DAS, a reduction in galling was observed in the Cartap hydrochloride 4% GR (1.22) and poultry manure (1.33) treated plants. Maximum root galling (4.4) was observed in the control plots followed by the NPK-treated plots. Except for the control group, all treatments proved to be effective ($p \leq 0.01$) in significantly reducing the number of root galls at all three observation dates, as shown in Table 4. The control group consistently had the highest number of galls in all three observations. Comparatively, the number of galls per plant was lower than the control in all treatments at 72, 105, and 120 DAS. At 120 DAS, the lowest number of root galls (1.22) was recorded in the Cartap hydrochloride-treated plots, followed by the poultry manure-treated plot (1.33). These two treatments did not show significant differences in their effectiveness in reducing RGI. The number of galls was drastically reduced in cantaloupe, as noted by Fard et al. (2019). Similarly, Pandey et al. (2019) reported the lowest number of galls in the okra plots treated with poultry litter. Das and Sinha (2005) also reported that application of poultry manure @ 5t/ha was found to be significantly effective in increasing yield of okra and reducing number of galls and egg masses of Meloidogyne incognita on okra.

Table 3. Effect of soil amendments on root gall index (RGI) of okra plant.

Treatments	Number of Galls Per Plant		
	72 DAS	105 DAS	120 DAS
Mustard oil cake	0.44±0.11^{de}	2.22±0.11^{d}	2.33±0.19^{c}
Poultry manure	0.11±0.11^{ef}	0.55±0.11^{e}	1.33±0.19^{d}
Goat manure	1.44±0.11^{c}	2.88±0.11^{c}	3.00±0^{b}
Vermi-compost	0.66±0.19^{d}	2.66±0^{c}	3.22±0.11^{b}
NPK	2.22±0.11^{b}	3.66±0.19^{b}	3.66±0.19^{b}
Cartap hydrochloride 4% GR	0.00^{f}	0.33±0.19^{e}	1.22±0.29^{d}
Control	2.77±0.11^{a}	4.55±0.11^{a}	4.4±0.29^{a}
$LSD_{0.05}$	0.38	0.32	0.65
CV (%)	19.7	7.7	13.3
f-value	74.87	207.38	31.75

Means within the column followed by the same letter are not significantly different at a 5% level of significance by DMRT. SEM = Standard Error of Mean, LSD = Least Significant Difference, and CV = Coefficient of Variation. Ns= non-significant.

3.4. Effects on Root Gall Index of Okra

The Root Gall Index (RGI) was evaluated at all three observation dates. Except for the control group, all treatments were highly effective ($p \leq 0.01$) in significantly reducing the RGI, as shown in Table 4. The control group consistently showed the highest RGI in all three observations. In particular, at 72 DAS, no root galls were observed in the plots treated with Cartap hydrochloride 4% GR. However, galls were observed, and the RGI increased to 105 and 120 DAS. The RGI was consistently lowest in the Cartap hydrochloride-treated plots, followed by poultry manure and mustard oil cake at 72, 105, and 120 DAS, respectively. Notably, there were no significant differences in RGI between the vermicompost and goat manure-treated plots at 105 and 120 DAS. The results of this study indicate a significant reduction in root gall index in plots treated with Cartap hydrochloride at 4% GR, followed by those treated with poultry manure and mustard oil cake. In contrast, the control plots had the highest RGI, followed by the NPK-treated plots. Although the RGI of plants treated with Cartap hydrochloride was the lowest, this reduction was not significantly different from the RGI observed in okra treated with poultry manure. Amulu and Adekunle (2018) stated that the highest rate of poultry manure significantly reduced root gall index and nematode population density, which could be attributed to the production of nematicide compounds during decomposition and increased activity of microbial antagonists in the soil. A study by Narayana et al. (2017) reported that Cartap hydrochloride 4% GR at a rate of 1 kg/ha was a statistically superior treatment for reducing the number of galls in cardamom. Cartap hydrochloride (4% GR) effectively reduces the nematode population and can serve as an environmentally friendly approach to root-knot nematode management in okra due to its non-persistent nature (Vinod et al., 2010). Poultry manure releases ammonia gas during decomposition, which has nematicide properties and is toxic to nematodes (Thoden et al., 2011).

Table 4. Effect of soil amendments on root gall index of okra plant.

Treatments	Gall Index		
	72 DAS	105 DAS	120 DAS
Mustard oil cake	0.55±0.11^{e}	2.33±0^{d}	2.55±0.11^{d}
Poultry manure	0.22±0.11^{f}	0.55±0.11^{e}	1.77±0.11^{de}
Goat manure	1.77±0.11^{c}	3.11±0.22^{c}	3.66±0.19^{c}
Vermicompost	1.44±0.11^{d}	3.22±0.22^{c}	3.44±0.11^{c}
NPK	2.22±0.11^{b}	5.44±0.11^{b}	5.44±0.11^{b}
Cartap hydrochloride 4% GR	0.00^{f}	0.66±0.38^{e}	1.55±0.58^{e}
Control	2.77±0.11^{a}	8.00±0.33^{a}	9±0.19^{a}
$LSD_{0.05}$	0.28	0.73	0.8
CV (%)	12.7	12.5	11.6
f-value	126.40	121.86	97.63

Means within the column followed by the same letter are not significantly different at a 5% level of significance by DMRT. SEM = Standard Error of Mean, LSD = Least Significant Difference, and CV = Coefficient of Variation. Ns = non-significant.

3.5. Effects on Fruit Yield (ton/ha) of Okra

The highest fruit yield (measured in tons per hectare) was obtained in the NPK-treated plot (60.62), followed by poultry manure (59.03) and mustard oil cake (48.49) as shown in Table 5. On the other hand, the lowest fruit yield (38.53 tons per hectare) was observed in the control followed by the plot treated with Cartap hydrochloride at 4% GR (42.82). Notably, there were no significant differences in fruit yield between the goat manure (46.53) and vermicompost (44.26) treated plots. This study has shown that the highest fruit yield of 60.62 tons per hectare was achieved in NPK-treated plots, closely followed by poultry manure at 59.03 tons per hectare and mustard oil cake at 48.49 tons per hectare. Conversely, the control plots had the lowest fruit yield at 38.53 tons per hectare. The significant improvement in vegetative growth and yield resulting from the application of poultry manure, mustard oil cake, and vermicompost can be attributed to several factors.

These include the introduction of nutrients into the soil as the organic matter decomposes, the direct effect of the decomposing material on nematodes, and the improved ability of roots to absorb water and essential nutrients required for photosynthesis (Lazarovits et al., 2001). The higher fruit yields observed in plots amended with poultry manure and mustard oil cake can be attributed to an improvement in soil fertility associated with organic amendments, as well as the release of nematode-toxic substances during the decomposition of these organic materials (Orisajo et al., 2008). The results also highlight the significant positive impact of poultry manure amendments on disease severity and overall fruit yield of okra (Pakeerathan et al., 2009). These results are consistent with previous research, particularly the work of Ogwulumba et al. (2010), which showed that tomato plants treated with organic amendments, including poultry manure, at rates ranging from 10 to 20 tons per hectare, produced a greater number of fruits per plant, resulting in an increased total yield compared to the control group.

Table 5. Effects of soil amendments on fruit yield (ton/ha) of okra plant.

Treatments	Yield (ton/ha)
Mustard oil cake	48.49±3.44^{bc}
Poultry manure	59.03±4.24^{ab}
Goat manure	46.53±1.35^{c}
Vermicompost	44.26±5.70^{c}
NPK	60.62±4.12^{a}
Cartap hydrochloride 4% GR	42.82±2.89^{c}
Control	38.53±4.28^{c}
$LSD_{0.05}$	11.57
CV (%)	13.4
f-value	4.86

Means within the column followed by the same letter are not significantly different at a 5% level of significance by DMRT. SEM = Standard Error of Mean, LSD = Least Significant Difference, and CV = Coefficient of Variation. Ns= non-significant.

4. Conclusion

The treatments showed significant differences in disease characteristics, plant growth, and yield. This could be a result of a significant amount of microorganisms present in the soil. Okra showed positive responses to various organic fertilizers in terms of plant growth, nematode control, and fruit yield. The research results indicated that the most effective treatment for reducing root-knot nematode disease and improving vegetative growth and yield of okra was a combination of poultry manure and mustard oil cake. Interestingly, there was no significant difference in their efficacy. On the other hand, the use of Cartap hydrochloride 4% GR reduced the severity of root-knot nematode infection but did not result in significant improvements in vegetative growth parameters or crop yield. Similarly, the use of synthetic fertilizers such as NPK resulted in the highest yield but did not reduce the level of root-knot nematode infection. Therefore, consistent use of inexpensive and environmentally friendly treatments that are readily available may prove to be a viable long-term solution. These treatments could be recommended as a sustainable alternative strategy in an integrated disease management approach aimed at maintaining a healthy environment, rather than relying on dangerous and long-lasting chemical nematicides.

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