



Optimizing Chili Pepper Growth and Yield: Comprehensive Evaluation of Effective Soil Amendments to Combat Root-Knot Nematodes

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ABSTRACT

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Capsicum species are cultivated globally as food, spice, therapeutic, cosmetic, and industrial resources. The cultivation of this essential crop is severely constrained by nematode infections. This study was set up using a completely randomized design to determine the effect of soil amendments on chili pepper. At 45 days after transplanting (DAT), plants that received Pig dung 12T/ha (i.e. 12 tons ha⁻¹), Cow dung 6T/ha, and Cow dung 12T/ha were significantly ($P \leq 0.05$) taller. Pig dung 12T/ha followed by all other treatments except Pig dung 6T/ha had significantly ($P \leq 0.05$) more leaves compared to Furadan+NPK. Plants that received Pig dung 12T/ha produced first open flowers 35.5 DAT, followed by those that received Furadan+NPK, Pig dung 6T/ha, Cow dung 6T/ha, and Poultry droppings 6T/ha. Pig dung 12T/ha produced highest ($P \leq 0.05$) shoot weight. More fruits ($P \leq 0.05$) were produced by Furadan+NPK treated plants followed by Cow dung 12T/ha, then Cow dung 6T/ha and Poultry droppings 12T/ha. The population of nematodes at 75 DAT was significantly ($P \leq 0.05$) lower in Pig dung 12T/ha, Pig dung 6T/ha, Poultry droppings 12T/ha, and Cow dung 6T/ha compared to the Control. All the soil amendments were effective against nematodes and augmented growth and yield of peppers.

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INTRODUCTION

Chili peppers (*Capsicum* species) in the plant family Solanaceae are crucial, versatile staple crops that have diverse uses in catering, medicinal, and manufacturing sectors worldwide. Resty et al. (2020) elucidated that one major constraint to pepper production is infection by nematodes like *Meloidogyne incognita*. *M. incognita* causes 12–90% yield loss depending on predisposing factors like initial nematode population density. Cultivar Revista (2016) concurred that the total damage inflicted on pepper depends on the nematode species, nematode population density, crop cultivar, temperature, type of soil, soil fertility, the agronomic practices, and previous crops planted on the plot. The following five *Capsicum* species are widely cultivated globally: *Capsicum annuum*, *C. baccatum*, *C. chinense*, *C. frutescens*, and *C. pubescens*.

Common cultural management practices like soil amendments, sanitation, fallowing, crop rotation, soil solarisation, and so on can make the environment less favourable for nematodes. Application of soil amendments boosts plant growth, plant health, water holding capacity, soil organic matter content, soil structure, infiltration, permeability of water, cation exchange capacity, and it improves the efficacy of natural enemies of nematodes which is not obtainable with synthetic fertilizer and nematicide combinations e.g. Furadan + NPK. Soil amendments include diverse types of plant-based compost, animal manures, plant oil cake, brewery waste, municipal waste, and sludge (Desaeger and Noling, 2019; Perry et al., 2019; Davis and Whiting, 2023). These organic soil amendments are excellent for organic and sustainable farming.

Nonetheless, the most effective principle against nematodes is integrated pest/pathogen management coupled with the principle of keeping inoculum potential low always. Based on common knowledge, cultural control using soil amendments works along with natural enemies (like *Bacillus subtilis* and *B. thuringiensis*), *Pseudomonas fluorescens*, *Paecilomyces lilacinus*, and *Pochonia chlamydosporia*) against nematodes. Biocontrol agents are eco-friendly alternatives to chemical nematicides, utilizing natural bacteria and fungi to suppress plant-parasitic nematodes, such as root-knot (Tatiana et al., 2021; Khan et al., 2023; Ayaz et al., 2024; Ara et al., 2024; Abd-Elgawad, 2021, 2025).

Soils with a diversity of beneficial microorganisms are more suppressive to pathogens than soils with little or no biological diversity. (Desaeger and Noling, 2019). Soil amendments may directly hinder the pathogenic species and/or reduce the nematode virulence. Soil amendments also encourage an increase in the population of beneficial organisms (Desaeger and Noling, 2019).

Dutta et al. (2019), and Abd-Elgawad (2021) reported that soil amendments promote rapid plant growth, which may lead to acquired tolerance against nematode infections. They affirmed that soil amendments boost the number of beneficial microbes,

including natural enemies of nematodes, as well as release nemato-toxic agents in the soil during decomposition.

Cultivar Revista (2016) further stated that the efficacy of soil amendments depends on the type of organic matter and the level of decomposition. Well-decomposed soil amendments are preferable. Abd-Elgawad (2021) recounted that the longevity of biocontrol depends on boosting the conditions under which the biocontrol agents operate especially by occasionally increasing the amount of soil amendments.

Organic vs. chemical nematode management in chili peppers has been studied before (Khan et al., 2023; Ara, 2024). This may be among the first comprehensive greenhouse trials reported from Nigeria. The local context and crop focus make it novel and valuable.

Based on the above discourse, this study aims to enhance plant health and improve plant growth by investigating the potential of soil amendments applied against nematodes on chili peppers. Consequently, adopting a constructive approach to managing nematodes in chili peppers involves evaluating a range of soil amendments to address root-knot nematode damage in chili crops effectively.

MATERIALS and METHODS

Study Site

This research was carried out at the greenhouse of Alex Ekwueme Federal University, Abakaliki, Ebonyi State (6.069°N x 8.199°E). The mainstay of most of the inhabitants of Ebonyi State is subsistence agriculture. The farmers cultivate many crops like chili peppers, cassava, yams, maize, sweet potato, Bambara groundnut, and fluted pumpkin. Abakaliki is in the undulating derived sub-humid tropical savannah ecological zone of Nigeria.

Preparation of The Soil And Soil Amendments

The soil used in this trial was obtained after scooping off the top 5 cm of the soil that contained lots of organic matter. The 3 loamy soil: 1 sand substrate used for this trial was steam sterilised using a cut metal drum and fuel-wood for 120 minutes. The steam sterilised soil was put in polythene bags after one month of airing it.

The soil amendments included 'fermented-bed' pig dung, cow dung, and poultry dropping. The cow dung was obtained in the form of dry farm yard manure available in the Faculty's cattle yard. The 'fermented-bed' technology developed by the staff of Animal Science Department of the University enables the production of pigs whose dung is devoid of foul smells. Thus, the pig dung utilized included basically organic bedding materials, dung, and the urine. Likewise, the poultry droppings came from the broiler unit and contained the litter plus the droppings.

Each of the soil amendments was pulverised into fine dust before incorporation in the soil at the determined weight and water was applied for decomposition to continue. The amendments were applied one week before transplanting of the chili peppers.

Preparation of The Seedlings

The seedlings were raised using a container. During the nursery stage, NPK 20:10:10 fertilizer was applied in the steam sterilised soil (3 loamy soil: 1 sand substrate) before sowing the seeds. The seedlings were grown for 30 days before transplanting. No insect infection was observed so no action was taken against arthropods. Seedlings of similar height and traits were used for the experiment.

Preparation of The Inoculant

The initial root knot nematodes were obtained from galled pepper roots. The pepper plants were uprooted from the farms in the campus. The galled roots were taken to the Faculty of Agriculture laboratory complex in polythene bags and processed to obtain the nematodes. Pepper roots were washed under running tap water. The eggmasses were teased off systematically. The female root-knot nematode was teased off and identified as outlined by Ndifon (2023).

The inoculant consisted of the bulked soil. To determine the number of eggs and 2nd stage juveniles (J2 juvenile nematodes), nematodes in 600 ml of the soil was extracted using the modified Baermann's funnel method. The extraction was continued for 6 days to ensure recovery of nematodes from the soil. The extracted nematodes were counted every day while extraction continued on the same soil sample (Ndifon et al., 2025). At the point of inoculation ascertained volumes of the soil were used to inoculate the soil at the base of the chili pepper plant. The inoculant was incorporated into the soil to avoid death of the nematodes.

Experimental Design

This greenhouse trial was conducted using a completely randomized design. The eight treatments consisted of two pig dung treatments at 6T/ha and 12T/ha, two cow dung treatments at 6T/ha and 12T/ha, two poultry droppings treatments at 6T/ha and 12T/ha, a Furadan (222.22 kg/ha) + NPK 20:10:10 treatment (444 kg/ha), and a negative control. Each treatment was replicated three times. The soil in each pot (30-cm diameter by 30 cm high) was inoculated using the same amount of the extracted nematodes. Each treatment had three pots in each replicate and the mean data was recorded from the three plants growing in three pots placed together in the replicate.

The trial was set up in this manner, the 30-days-old pepper seedlings were transplanted and the nematode inoculum (circa 4060 eggs/juvenile nematodes) was applied immediately after transplanting. The supernatant was applied under the base

of each one-week-old seedling using a pipette pump at transplanting time (Ndifon, 2023; Ndifon et al., 2025). It takes time for the nematodes to locate the roots but the injured roots may release more leachates that the nematodes can easily locate.

Data Collection And Analysis

Data were collected on shoot height (cm) using a flexible tape, number of branches, shoot weight (g) was collected using a Mettler balance, number of days to first flower (the plant exhibited indeterminate growth), number of leaves, number of nematodes in the soil at termination of the trial. The number of nematodes and the reproductive factor were determined using the method described by Ndifon (2023) and Ndifon et al. (2025). The reproductive factor is simply obtained by dividing the final nematode population obtained at the termination point of the trial over the initial nematode population used to inoculate the soil.

Data were collected thrice (1st, 2nd and 3rd data at 45, 60, and 75 days after transplanting (DAT) respectively) except where stated otherwise. The data were subjected to analysis of variance (ANOVA) and the means separated using Genstat 2nd Edition Discovery (The VSNi Team, 2023) and IBM SPSS (statistical package for social sciences) version 26 (IBM Corp, 2019). The means were separated using Duncan’s multiple range test (DMRT) at $P \leq 0.05$.

RESULTS and DISCUSSION

The effect of soil amendments on the shoot height of *Meloidogyne* species infected chili peppers in the greenhouse is presented in Figure 1. It reveals that during the early growth of the peppers Pig dung 12T/ha, Cow dung 6T/ha, and Cow dung 12T/ha produced significantly ($p \leq 0.05$) taller plants.

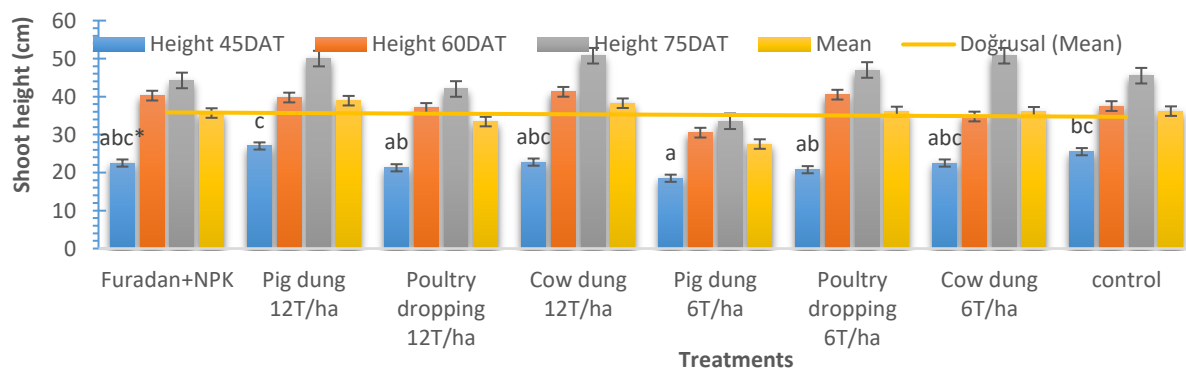


Figure 1. Effect of soil amendments on the shoot height of chili peppers infected by *Meloidogyne* species

*Means followed by the same letter(s) in a column are not significantly different (based on Duncan’s Multiple Range Test at $P \leq 0.05$).

Effect of soil amendments on the number of leaves of *Meloidogyne* species infected chili peppers is presented in Figure 2. It was observed that all treatments except Pig dung 6T/ha had significantly ($P \leq 0.05$) more leaves compared with Furadan + NPK. Throughout the study plants that received Cow dung tended to have fewer leaves ($P \leq 0.05$) compared to those plants that received Furadan + NPK or other soil amendments.

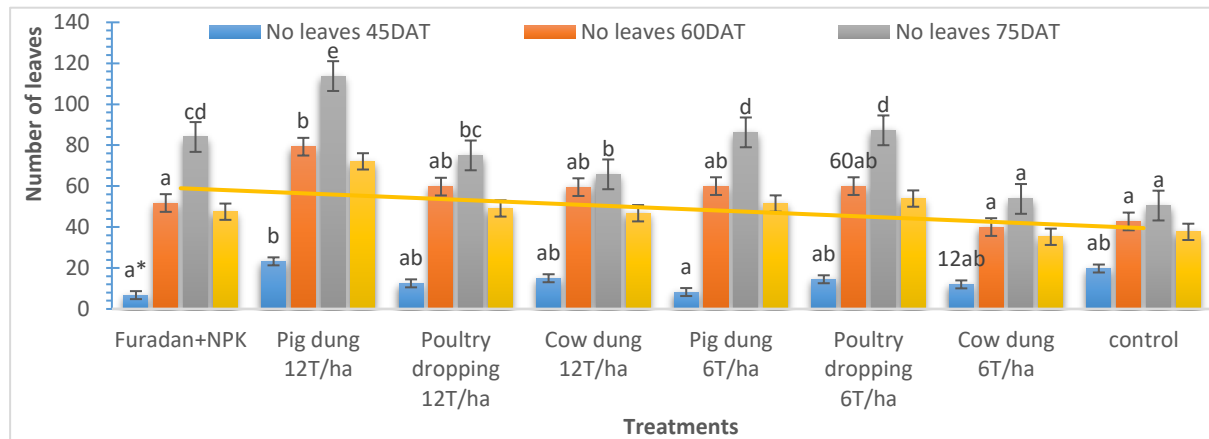


Figure 2. Effect of soil amendments on the number of leaves of chili peppers infected by *Meloidogyne* species

*Means followed by the same letter(s) within a column are not significantly different according to Duncan’s Multiple Range Test (DMRT) at $P \leq 0.05$.

Effect of soil amendments on the number of days to produce the first open flower on *Meloidogyne* species infected chili peppers is presented in Figure 3. It reveals that plants that received Pig dung 12T/ha produced first open flower at 35.5 DAT. This was significantly ($P \leq 0.05$) lower compared to all other treatments. This performance was followed by Furadan + NPK and Pig dung 6T/ha, Cow dung 6T/ha, and Poultry droppings 6T/ha, finally, Cow dung 12T/ha and Poultry droppings 12T/ha compared to the Control which took 66.3 DAT to produce the first open flower.

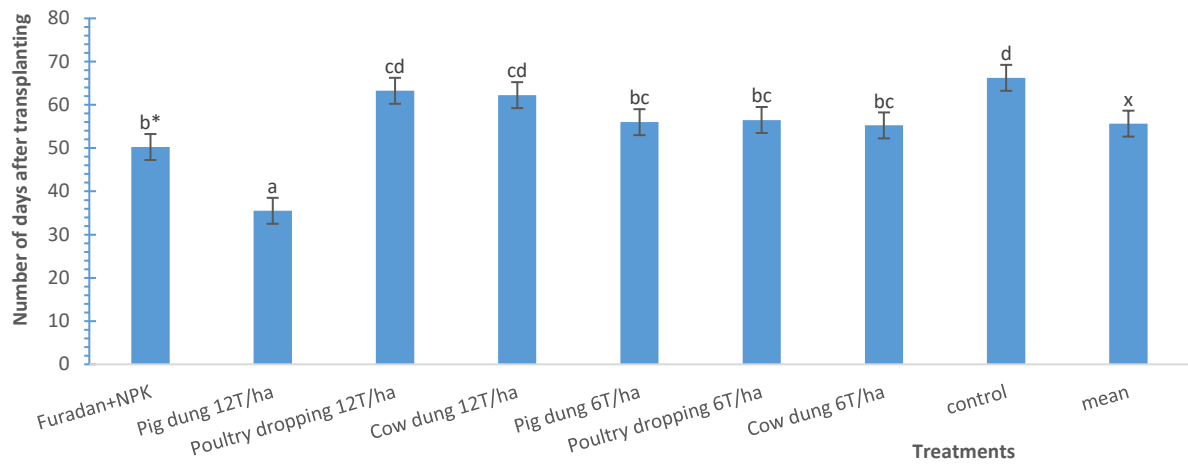


Figure 3. Effect of soil amendments on the number of days after transplanting to produce the first open flower of chili peppers infected by *Meloidogyne* species.

*Means followed by the same letter(s) within a column are not significantly different according to Duncan’s Multiple Range Test (DMRT) at $P \leq 0.05$.

The effect of soil amendments on the shoot weights of *Meloidogyne* species infected chili peppers is presented in Figure 4. It is observed that Pig dung 12T/ha produced significantly ($P \leq 0.05$) highest shoot weight compared to all the other treatments. This performance was followed by that of Pig dung 6T/ha and Poultry droppings 6T/ha. Cow dung at 6T/ha and 12T/ha produced lower ($P \leq 0.05$) shoot weights which was statistically similar to Furadan + NPK and Poultry droppings 12T/ha.

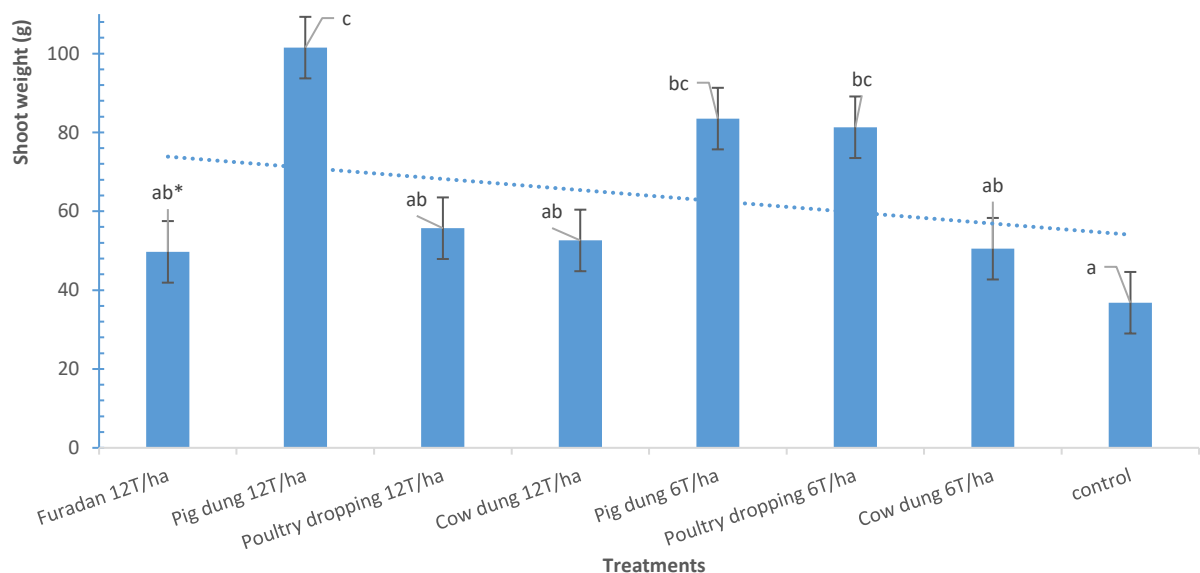


Figure 4. Effect of soil amendments on the shoot weights of chili peppers at 75 Days after transplanting

*Means followed by the same letter(s) within a column are not significantly different according to Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.

The effect of soil amendments on the number of primary branches produced by *Meloidogyne* species infected chili peppers is presented in Figure 5. It reveals that Pig dung 12T/ha produced more branches than all other treatments. Some treatments gave below average number of primary branches compared to the control but this was not significantly different ($P \leq 0.05$).

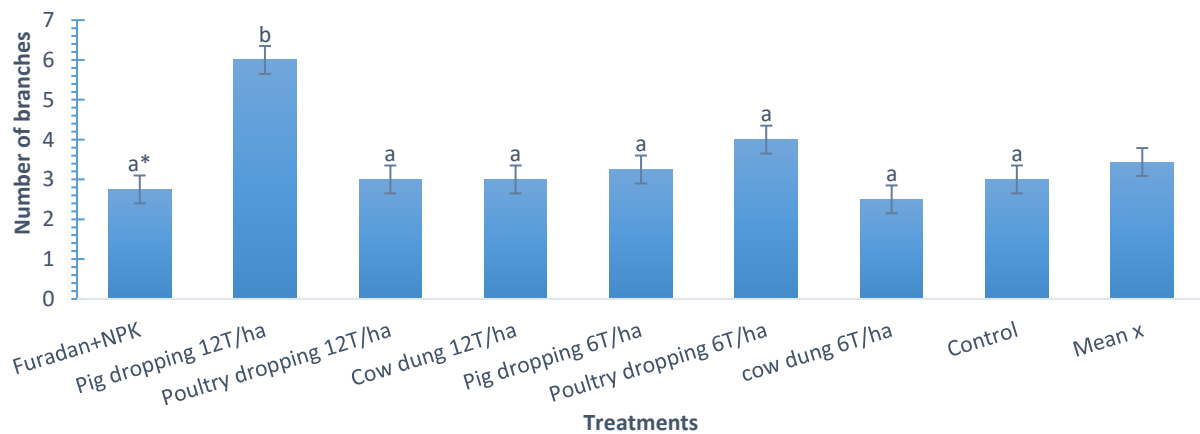


Figure 5. Effect of soil amendments on the number of primary branches (only) produced by chili peppers at 75 days after transplanting

*Means followed by the same letter(s) within a column are not significantly different according to Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.

Effect of soil amendments on the number of fruits and fruit weights produced by *Meloidogyne* species infected chili peppers is presented in Figure 6. The number of fruit weights were significantly ($p \leq 0.05$) highest in Furadan + NPK treated plants followed by Cow dung 12T/ha, then Cow dung 6T/ha and Poultry droppings 12T/ha. Belay et al. (2023) effectively utilised vermicompost and moringa to control nematodes and boost plant weight. This corroborates the findings of this study on pepper which showed that soil amendments control nematodes and boost plant yield. Al-Fraih. (2015) reported significant differences in number of leaves, shoot weight, especially with the application of garlic straw treatment. This concurs with the findings herein that soil amendments affect leaf count and shoot weight positively.

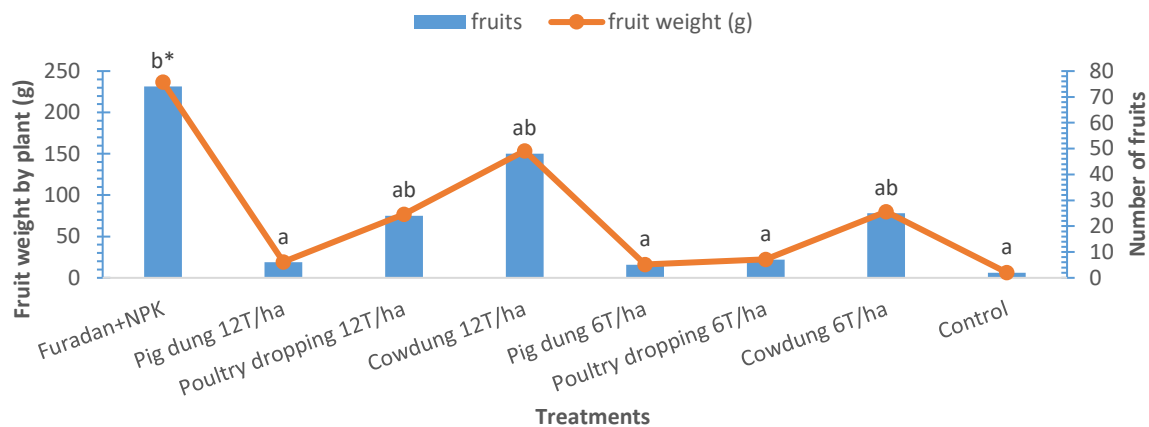


Figure 6. Effect of soil amendments on the number of fruits and fruit weights produced by chili peppers at 75 days after transplanting

*Means followed by the same letter(s) within a column are not significantly different according to Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.

Pepper was a good host to the nematode based on the nematode population at point of termination of the trial however, the soil amendments reduced the reproduction as shown using the reproductive factor. The reproductive factor (calculated using the initial nematode population and final nematode population) was significantly highest ($P \leq 0.05$) in the Control (Figure 7).

Soil amendments alter the C: N ratio, reducing nitrogen availability and thereby suppressing nematodes. Suppression of root knot nematodes by soil amendments was revealed in this trial which corroborates the findings of Elele et al. (2016). The reported that nematode populations were reduced with application of soil amendments.

Many materials, such as oil cakes, sawdust, coffee husks, crustacean skeletons, chicken manure, paper waste, and crop residues control plant parasitic nematodes effectively ($P \leq 0.05$) (Sikora and Roberts, 2018).

Similarly, Aji (2023) reported that soil amendments (dried leaves, seed powders and cakes, tree fibers, and green manures) have potential to kill nematodes. These findings confirm the outcomes of this current trial that organic soil amendments effectively control nematodes. The soil amendments successfully reduced the reproductive factor especially at higher concentrations of the soil amendments. However, Al-Fraih (2015) observed no significant difference in plant height, stem diameter, tomato fruit yield, and Root knot index among treatments which tends to contradict the current findings on these parameters. Al-Fraih reported highest nematode populations when bokashi plus garlic straw was applied the compared to the other treatments.

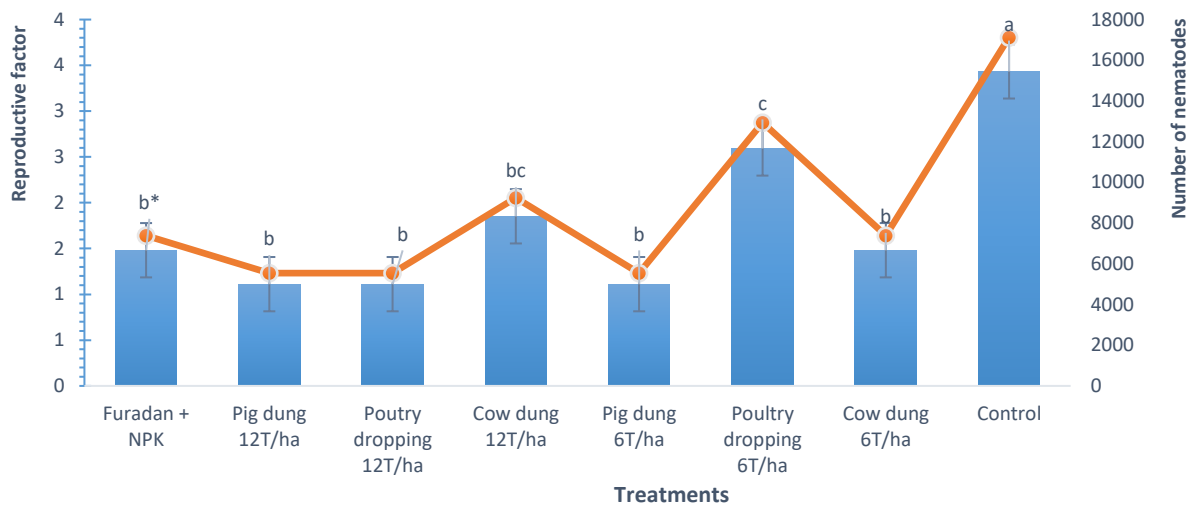


Figure 7. The number of nematodes in soil under chili pepper in the greenhouse

*Means followed by the same letter(s) within a column are not significantly different according to Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$.

CONCLUSION and RECOMMENDATION

Unlocking the full potential of chili pepper cultivation was assessed through a rigorous analysis of powerful soil amendments that decisively controlled root-knot nematodes for healthier, more productive plants. The soil amendments (i.e. Pig dung, Poultry droppings, and Cow dung) effectively controlled the nematodes and reduced their reproduction efficiency. The findings of this study revealed that nematodes can be effectively controlled using organic soil amendments as compared to the synthetic nematicide+synthetic fertilizer (check/standard). The organic soil amendments may act as sustainable alternatives to Furadan+NPK even though they produced less yield. The organic soil amendments are recommended for organic farming. Overall, the merits of greenhouse research (sterile soil and controlled temperature) would be challenged under field conditions which may influence the results obtained. Future studies should validate these findings under field conditions and explore long-term soil health impacts.

Conflict of Interest

The authors have declared no conflict of interest.

Data Availability Statement

All the data generated were presented in this article consequently no raw data were left. No unnecessary derived figures and tables were included in this work but ANOVA tables, degrees of freedom, F-value, standard error, and coefficient of variation may be made

available to researchers based on reasonable request. These figures would have added clutter and reduced flow and readability.

Authors' Contributions

EMN contributed to the project idea, design and execution of the study. EMN, CPOE, COE conducted the greenhouse execution and analyses. EMN and CPOE supervised the experiment. EMN wrote the manuscript.

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