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Research Article

Context-dependent Effects of Fosthiazate on Soil Nematode Communities and Soil Properties in Guava Orchards with Contrasting Nematode Infestation Histories

Thippawan Korsrisakul, Natthidech Beesa, Phornthawon Phanbut, Anongnuch Sasnarukkit and Buncha Chinnasri*
Department of Plant Pathology, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand

Arunee Suwanngam
Tropical Agriculture Program, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand

* Corresponding author. E-mail: agrbcc@ku.ac.th DOI: 10.14416/j.asep.2026.07.016
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Abstract
Fosthiazate is widely used to control plant-parasitic nematodes in perennial orchards; however, its ecological effects on non-target soil communities may depend on baseline soil conditions. This study evaluated the short-term impacts of fosthiazate on soil nematode communities and soil physicochemical properties in two guava (*Psidium guajava* L.) orchards with contrasting *Meloidogyne enterolobii* infestation histories. Treatments included an untreated control, the recommended rate (2 kg a.i. ha^{-1}), and a high rate (3 kg a.i. ha^{-1}), with sampling conducted before and 1.5- and 3-months after application. Fosthiazate induced dose- and time-dependent changes in both orchards, but responses differed between infestation histories. In the non-infested orchard, higher rates were associated with relatively stable ecological indices and maintenance of higher trophic groups. In contrast, the infested orchard exhibited reduced enrichment and structure indices together with greater temporal variability in nematode community composition, indicating a comparatively simplified soil food web. Multivariate analyses revealed that community shifts were associated primarily with soil organic matter, total nitrogen, and available phosphorus in the non-infested orchard, whereas soil pH and physicochemical constraints were more strongly associated with community variation in the infested orchard. These findings demonstrate that the ecological effects of fosthiazate vary according to pre-existing soil conditions and nematode infestation history. Incorporating nematode-based ecological indicators into nematicide management may support more sustainable and ecologically informed pest management strategies in perennial orchard systems.

Keywords: Nematicide application, Orchard soil ecology, Root-knot nematodes, Soil health indicators, Soil nematodes

1 Introduction

Guava (*Psidium guajava* L.), a member of the family Myrtaceae, is a commercially valuable fruit crop native to southern Mexico and Central America [1]. Due to its exceptional nutritional and medicinal properties, including high concentrations of vitamin C, provitamin A, calcium, phosphorus, and antioxidants [2],[3], guava is now widely cultivated across tropical and subtropical regions worldwide [4]-[7]. Its fruits are consumed fresh or processed into products such as juices, jams, and dried snacks, contributing significantly to household income and export economies in many countries.

In Thailand, guava cultivation has expanded rapidly over the past decades, particularly in Ratchaburi, Nakhon Pathom, and Samut Sakhon provinces. According to recent agricultural statistics, guava production in Thailand reached approximately 7,000 tons in 2025, with an export value of approximately 6.15 million USD [7]. However, the intensification of guava production has resulted in increasing reliance on chemical fertilizers and pesticides to maintain yields and suppress pests and diseases.

Excessive and continuous agrochemical use may adversely affect soil health by altering soil physicochemical properties and disrupting biological processes associated with longterm soil fertility and ecological stability [8]-[10].

Soil health is broadly defined as the capacity of soil to function as a living ecosystem that sustains plant productivity, supports biodiversity, and regulates water and nutrient cycles within a defined land use system [11]. In recent years, increasing attention has been given to biological indicators for evaluating soil health, due to their sensitivity to environmental disturbances and their ability to reflect changes in ecosystem functioning [12]-[14]. Among these indicators, nematodes occupy a central role in soil ecosystems due to their high abundance, taxonomic diversity, and trophic versatility. Free-living nematodes, such as *Cephalobus* spp., contribute to important ecosystem functions including microbial regulation, organic matter decomposition, and nutrient cycling, whereas plant-parasitic nematodes—particularly species of the genus *Meloidogyne—can* cause significant economic damage in fruit crops, including guava [15]-[18]. Therefore, the composition and trophic structure of nematode communities provide valuable insight into soil ecological conditions and environmental disturbance.

Fosthiazate, a broad-spectrum organo phosphorus nematicide, is widely used for the management of root-knot nematodes (*Meloidogyne* spp.) and other plant-parasitic nematodes in commercial fruit production systems [19]-[21]. Compared with fumigant nematicides, fosthiazate exhibits relatively rapid degradation in soil, reducing the risk of long-term residue accumulation and supporting its integration into intensive cropping systems [22]. Despite its effectiveness against target nematodes, fosthiazate may also affect non-target soil organisms, including free-living nematodes and other beneficial components of the soil food web [23]-[26]. Such disturbances may alter nutrient cycling, microbial interactions, and trophic structure, thereby influencing overall soil ecosystem functioning. Previous studies have demonstrated that nematode community composition responds rapidly to environmental and chemical disturbances, supporting their use as reliable bioindicators of soil condition and ecological resilience [27], [28]. However, limited information is available regarding whether ecological responses to nematicide application differ according to prior nematode infestation history and baseline soil condition in perennial orchard systems.

Therefore, this study aimed to evaluate the effects of fosthiazate application on soil nematode community structure, ecological indices, and soil physicochemical properties in guava orchards with contrasting histories of root-knot nematode infestation. By comparing infested and non-infested orchard systems under identical application regimes, this study sought to determine whether nematicide-induced ecological responses are influenced by baseline soil conditions. We hypothesized that fosthiazate would alter nematode community composition and soil nutrient dynamics, but that the magnitude and direction of these responses would differ depending on prior nematode infestation history and pre-existing soil ecological conditions.

2 Materials and methods

2.1 *Study sites and experimental design*

The study was conducted in two commercial guava orchards located in Sam Phran District, Nakhon Pathom Province, Thailand. One orchard had no documented history of root–knot nematode infestation (non-infested orchard; NRKN). The second orchard had a documented history of *Meloidogyne enterolobii* infestation reported in 2012 (root-knot nematode-infested orchard; RKN) [29]. The experiment followed a randomized complete block design (RCBD) with three replicate plots per orchard. Within each plot, three guava trees were selected for soil sampling and treatment application.

Fosthiazate (Nemathorin 10% GR), a granular organophosphate nematicide, obtained from Erawan Agricultural Chemicals Co., Ltd. and Ishihara Sangyo Kaisha, Ltd., was applied at three rates: 0 kg a.i. ha^{-1} (control), 2 kg a.i. ha^{-1} (recommended rate; equivalent to 1.57 g $plant^{-1}$), and 3 kg a.i. ha^{-1} (high rates; equivalent to 2.35 g $plant^{-1}$). The nematicide was evenly broadcast on the soil surface within a 50-cm radius around each tree and lightly incorporated into the soil.

Soil samples were collected before application (0 months) and at 1.5 and 3 months after application. These sampling intervals were selected to capture short-term ecological responses during the expected active period and early degradation phase of fosthiazate in soil.

2.2 *Soil sampling and nematode extraction*

At each sampling time, five soil subsamples were collected from the rhizosphere zone (0-30 cm depth) around each treated tree using a hand trowel and composited into a single sample. Samples were transported to the Nematology Laboratory, Faculty of Agriculture, Kasetsart University, for analysis.

Nematodes were extracted from 300 g of fresh soil using a modified Baermann funnel technique for 48 h [30]. Extracted nematodes were heat-killed, fixed in hot triethanolamine–formaldehyde (TAF) solution, and processed into glycerin according to the Seinhorst method [31]. Permanent slides were prepared for morphological identification to the family level using a stereomicroscope (Olympus SZ61, Japan) and a compound microscope (Olympus CX33, Japan).

2.3 *Nematode community analysis and ecological indices*

Nematodes were classified into trophic groups including bacterivores, fungivores, herbivores, omnivores, and predators. Colonizer–persister (c–p) values were assigned according to the classification systems of Bongers [32], where c-p 1 represents opportunistic colonizers and c-p 5 represents disturbance-sensitive persister taxa.

Ecological indices, including Shannon diversity index (H'), Simpson index, Maturity Index (MI), Maturity Index 2–5 (MI2–5), Plant-parasitic Index (PPI), Basal Index (BI), Channel Index (CI), Enrichment Index (EI), and Structure Index (SI) were calculated using the NINJA online software version 1 [33].

2.4 *Soil physiochemical analysis*

Soil samples collected at 0 and 3 months after application were air-dried, sieved through a 2-mm mesh, and analyzed to characterize soil physicochemical properties. For each treatment, subsamples from biological replicates were pooled into composite samples prior to analysis.

Soil pH was determined using a 1:1 soil-to-water ratio with a pH meter (LAQUA F-71, Horiba, Japan). Electrical conductivity (EC) was measured using an EC meter (FiveEasy, Mettler Toledo, Switzerland). Organic matter (OM) was determined using the Walkley and Black method [34], whereas total nitrogen (N) was analyzed using the Kjeldahl method [35]. Available phosphorus was determined using the Bray II extraction method [36].

Exchangeable potassium (K), calcium (Ca), and magnesium (Mg) were analyzed using atomic absorption spectrophotometry following extraction with 1 N NH_4OAc (pH 7.0) [37]. Soil texture was determined using the hydrometer method [38]. All soil physicochemical analyses were conducted at the Soil Science Laboratory, Faculty of Agriculture, Kasetsart University, Kamphaeng Saen Campus.

2.5 *Statistical analysis*

Changes in nematode abundance and ecological indices were expressed as delta values relative to baseline measurements (0 months) and analyzed using linear mixed models (LMMs). In all models, treatment and sampling time were treated as fixed factors, whereas block and replicate were included as random effects. Significant differences among means were determined using Tukey's HSD test at $p < 0.05$. Data normality and homogeneity of variance were assessed using Shapiro-Wilk and Levene's tests, respectively.

Differences in nematode community composition were evaluated using non-metric multidimensional scaling (NMDS) based on Bray–Curtis dissimilarity and tested using permutational multivariate analysis of variance (PERMANOVA). Redundancy analysis (RDA) was performed to examine relationships between nematode communities and soil physicochemical variables. All statistical analyses were conducted in R version 4.3.1 using the vegan and ggplot2 packages.

3 Results and discussion

3.1 *Nematodes community composition and trophic structure*

Across all sampling times and treatments, 16 nematode families were identified in the non–infested orchard (NRKN), whereas 21 families were recorded in the root–knot nematode–infested orchard (RKN). These nematodes were classified into five trophic groups: herbivores, bacterivores, fungivores, omnivores, and predators (Figure 1). Herbivorous nematodes were represented mainly by Meloidogynidae, Hoplolaimidae, Tylenchidae, and Pratylenchidae, whereas bacterivores were dominated by Rhabditidae and Cephalobidae. In the NRKN orchard, herbivorous and omnivorous nematodes were dominant throughout the sampling period (Figure 1 and 2).

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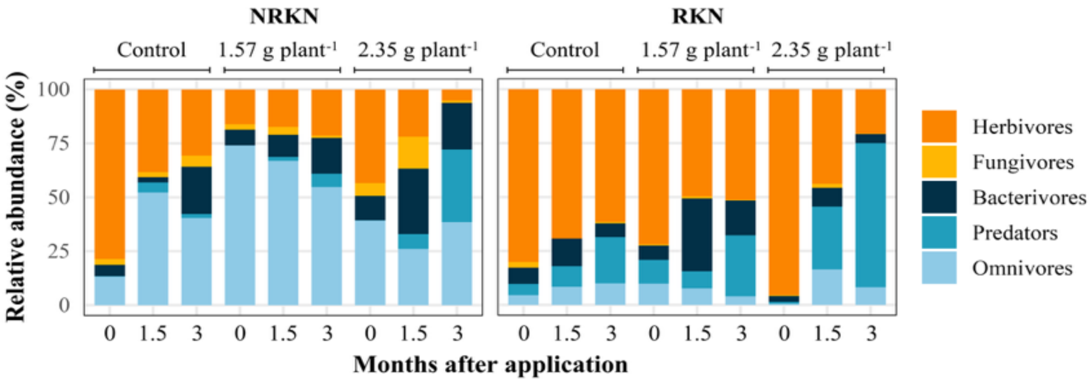

Figure 1: Relative abundance of nematode trophic groups in non-infested (NRKN) and root-knot nematode-infested (RKN) guava orchards at 0, 1.5, and 3 months after application. Treatments include control, 1.57 g plant^{-1}, and 2.35 g plant^{-1}.

Following fosthiazate application, moderate fluctuations in trophic composition were observed across treatments and sampling times. Bacterivorous nematodes showed slight increases at 1.5 months after application, whereas fungivorous, omnivorous, and predatory groups remained relatively stable throughout the experiment.

At 3 months after application, herbivorous nematodes remained one of the dominant trophic groups in all treatments. Predator abundance increased under the high-rate treatment, suggesting a delayed response of higher trophic levels, while fungivores showed some divergence between application rates over time.

In contrast, the RKN orchard showed greater temporal variation in trophic composition following fosthiazate application (Figure 1 and 2). Herbivorous nematodes were dominant prior to treatment and remained abundant throughout the study period, although their relative abundance declined at 1.5 months after application under the high application rate. Bacterivorous and fungivorous nematodes fluctuated among treatments over time, whereas omnivorous and predatory groups remained consistently low across all sampling periods.

The contrasting trophic patterns observed between orchards suggest that prior infestation history and baseline ecological conditions may influence nematode community responses following chemical disturbance. The NRKN orchard maintained a comparatively balanced trophic composition throughout the study period, whereas the RKN orchard remained dominated by lower trophic groups. Similar shifts in trophic organization following nematicide application have been reported in previous studies of agriculturally disturbed soils [23]-[26].

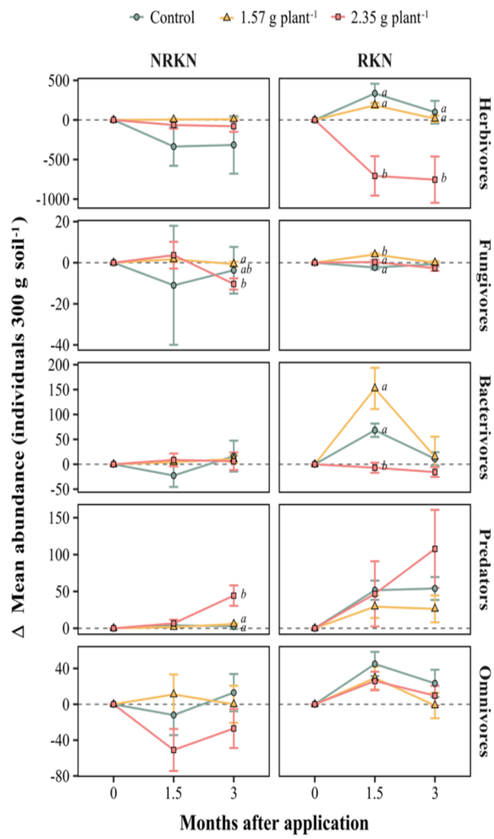

Figure 2: Temporal changes in mean abundance of nematode trophic groups abundance in non-infested (NRKN) and root-knot nematode–infested (RKN) guava orchards following fosthiazate application. Treatments include control, 1.57 g plant^{-1}, and 2.35 g plant^{-1}. Values represent mean change from the baseline (0 months).

3.2 *Nematode diversity and ecological indices*

Based on ecological indices (Figure 3) and faunal profile analysis (Figure 4) following Ferris *et al.,* [27], the effects of fosthiazate on soil nematode communities differed according to the initial ecological condition of each orchard.

In the NRKN orchard, the nematode community demonstrated a relatively high degree of ecological stability following fosthiazate application. The Shannon diversity index (H′) remained relatively stable across treatments, with only a transient increase observed at 1.5 months under the high application rate. This overall stability was further reflected by MI 2-5 and SI values, which remained comparatively consistent throughout the study period, indicating that the general organization of the soil food web was largely maintained. Faunal profile analysis positioned most samples within the structured and moderately enriched quadrants, corresponding to a relatively mature and functionally regulated system. A temporary increase in EI at 1.5 months may reflect a short-term enrichment response associated with increased microbial activity following disturbance. However, this response was transient, and ecological indices subsequently returned closer to baseline conditions. These observations were consistent with the relatively limited fluctuations observed in trophic group composition, where no strong directional shifts occurred among bacterivores, fungivores, omnivores, or predators. Collectively, these patterns suggest that fosthiazate induced primarily short-term functional responses in the NRKN orchard without substantially disrupting overall soil food web organization. Compared with some conventional nematicides that have been reported to cause broader reductions in soil food web complexity and microbial activity [9], [39], the ecological responses observed following fosthiazate application appeared comparatively moderate and strongly dependent on baseline soil condition. Previous studies have similarly reported that fosthiazate mainly induces short-term shifts in rhizosphere biological communities rather than persistent ecological disruption [40].

In contrast, the RKN orchard exhibited greater temporal variability in ecological indices following fosthiazate application. The H′ fluctuated more markedly over time, indicating shifts in community composition after treatment. Changes in MI2-5 and SI suggested moderate alterations in food web structure during the early sampling period, although higher trophic groups such as omnivores and predators remained comparatively limited throughout the experiment.

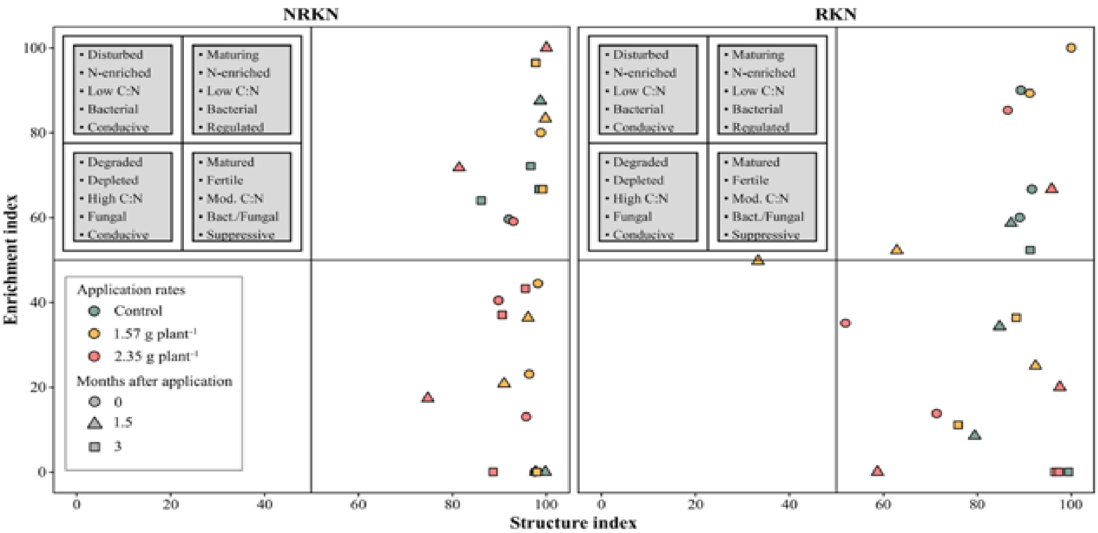

Figure 4: Faunal profile analysis of nematode communities based on enrichment index and structure index in non-infested (NRKN) and root-knot nematode–infested (RKN) guava orchards following fosthiazate application. Treatments include control, 1.57 g plant^{-1}, and 2.35 g plant^{-1}. Quadrants represent functional metabolic conditions of the soil food web: enriched/disturbed (upper left), structured/maturing (upper right), degraded/depleted (lower left), and structured/matured (lower right).

Changes in MI2-5 and SI suggested moderate alterations in food web structure during the early sampling period, although higher trophic groups such as omnivores and predators remained comparatively limited throughout the experiment. The PPI remained relatively stable, indicating that plant-parasitic nematodes continued to be present but did not solely drive community-level changes. Faunal profile analysis revealed a temporal shift toward higher SI and EI values together with moderate fluctuations in trophic groups, indicating short-term adjustments within the soil food web. Nevertheless, the relatively low abundance of higher trophic groups indicated that the nematode community in the RKN orchard remained less structured than that of the NRKN orchard throughout the study period. This pattern may reflect lower ecological buffering capacity in soils previously affected by root-knot nematode infestation, where simplified trophic organization can increase sensitivity to chemical disturbance.

Overall, these findings indicate that fosthiazate application was associated with distinct ecological responses depending on baseline soil condition and infestation history. The NRKN orchard exhibited comparatively stable ecological characteristics following disturbance, whereas the RKN orchard showed greater temporal variability and evidence of community reorganization following treatment.

3.3 *Soil physiochemical properties*

Soil chemical properties differed between orchards following fosthiazate application (Table 1).

In the NRKN orchard, which had previously been managed using bioluminescent mushroom applications, organic matter (OM), total nitrogen (N), and available phosphorus (P) increased at 3 months after application under the high application rate. These increases may reflect enhanced nutrient turnover and biomass decomposition following disturbance. The relatively stable trophic structure observed in the NRKN orchard suggests that pre-existing biologically active soil conditions may have contributed to maintaining nutrient dynamics following fosthiazate application. In contrast, EC values decreased across treatments over time, whereas soil pH and Ca remained comparatively stable.

In the RKN orchard, OM, N, and P generally declined over time across treatments, with more pronounced reductions observed under the high application rate. This pattern was consistent with the findings of Chen *et al.,* [9], who reported that fosthiazate may influence nitrogen mineralization processes associated with bacterivorous nematodes and soil biological activity. Although EC and K increased at 3 months after application, major nutrient parameters generally decreased throughout the study period.

Table 1: Soil physicochemical properties of non-infested (NRKN) and root-knot nematode–infested (RKN) guava orchards at different fosthiazate application rates and sampling times.

Soil properties	Control		1.57 g/plant		2.35 g/plant	
	0	3	0	3	0	3
NRKN orchard						
pH	6.06	6.59	6.35	6.07	6.92	6.76
EC	4.45	2.93	3.42	2.91	2.81	0.78
OM	2.4	2.54	2.5	2.81	2.27	4.7
P	214	314	287	417	260	1914
K	753	777	769	641	1070	762
Ca	12599	4543	4596	4625	2598	5509
Mg	918	860	1360	806	1884	800
N	0.12	0.17	0.14	0.16	0.17	0.29
RKN orchard						
pH	6.25	6.58	6.4	6.74	6.15	6.9
EC	1.11	0.96	1.27	0.63	1.36	3.28
OM	5.64	6.13	5.01	3.27	4.46	2.77
P	1391	1115	1736	1313	2486	654
K	804	642	1372	515	686	1071
Ca	5212	5520	4218	5392	5158	3893
Mg	1374	734	1693	877	1252	932
N	0.29	0.27	0.29	0.29	0.26	0.19

Soil pH, Ca, and Mg exhibited relatively limited variation among treatments. These responses suggest reduced nutrient turnover potential and weaker biological regulation within the simplified soil food web observed in the RKN orchard.

Previous studies have shown that nematicides can indirectly alter soil nutrient dynamics through changes in microbial activity and decomposition processes [9], [25], [39]. In the present study, the contrasting nutrient responses observed between orchards suggest that baseline soil condition influenced the short-term physicochemical responses following fosthiazate application. Nevertheless, because the present study evaluated short-term responses only, the observed changes should be interpreted as transient physicochemical responses rather than long-term improvements or degradation of soil quality.

Overall, these contrasting responses indicate that fosthiazate altered soil nutrient dynamics in a context-dependent manner, with ecological responses differing according to baseline soil condition and infestation history.

3.4 *Multivariate analysis of nematode community structure*

Multivariate analyses using NMDS ordination and RDA revealed distinct patterns of nematode community organization associated with environmental conditions in each orchard (Figure 5). NMDS stress values were low and comparable between orchards (NRKN = 0.155; RKN = 0.157), indicating reliable ordination of community structure.

In the NRKN orchard (Figure 5a), NMDS ordination showed relatively clustered communities with limited temporal displacement following fosthiazate application. Several taxa, including Cephalobidae, Rhabditidae, and Dorylaimidae, were significantly associated with community structure (p-value < 0.01). RDA further demonstrated that community variation was strongly associated with organic matter (OM), total nitrogen (N), available phosphorus (P), and electrical conductivity (EC) (p-value ≤ 0.003) (Figure 5c), indicating close relationships between nutrient-related variables and nematode community composition.

The RKN orchard exhibited greater dispersion and temporal variability in NMDS ordination patterns (Figure 5b), suggesting stronger shifts in community organization following treatment. Key taxa associated with community structure included Meloidogynidae, Pratylenchidae, and Tripylidae (p-value ≤ 0.001). RDA analysis (Figure 5d) indicated that community variation was associated primarily with soil pH (p-value = 0.001), together with phosphorus (P) and magnesium (Mg) (p-value ≤ 0.005). Although OM also showed a moderate association (p-value = 0.021), the overall pattern suggested a stronger influence of physicochemical constraints relative to nutrient-associated gradients. These findings are consistent with previous studies demonstrating that nematode community structure is closely associated with nutrient availability and biological processes in relatively structured soils [41]-[43].

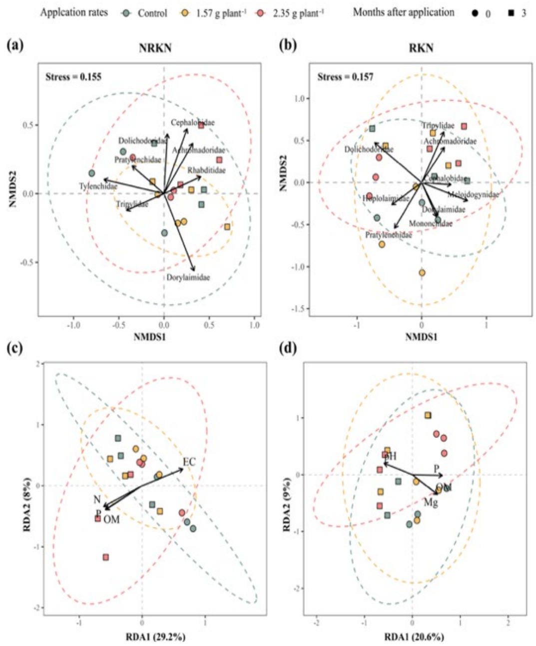

Figure 5: Multivariate analyses of nematode communities and soil physicochemical properties in non-infested (NRKN) and root-knot nematode–infested (RKN) guava orchards. Non-metric multidimensional scaling (NMDS) ordinations illustrate community structures in (a) NRKN and (b) RKN orchards. Redundancy analysis (RDA) biplots showed the relationships between nematode communities and soil physicochemical properties in (c) NRKN and (d) RKN orchards. Treatments include control, 1.57 g $plant^{-1}$, and 2.35 g $plant^{-1}$. Ellipses represent 95% confidence intervals for each treatment group.

In the present study, this relationship was reflected in the NRKN orchard, where community variation was strongly associated with OM, N, and P.

The relatively stable and nutrient-associated structure observed in this orchard may also be related to its previous management history, including bioluminescent mushroom application, which may have contributed to increase organic inputs and biologically active soil conditions.

In contrast, soil pH has frequently been identified as an important factor influencing soil biota under disturbed or environmentally constrained conditions [44], [45]. which was consistent with the observed pattern in the RKN orchard. Furthermore, disturbance-associated restructuring of soil food webs has been linked to reduced trophic complexity and greater physicochemical control over biological communities [46]. Collectively, these multivariate patterns support the interpretation that ecological responses to fosthiazate differed according to baseline soil condition and infestation history.

4 Conclusion

This study demonstrates that the effect of fosthiazate on soil nematode communities and soil nutrient dynamics were strongly context-dependent and influenced by the initial ecological condition of each orchard.

In the NRKN orchard, which was characterized by a relatively mature and structurally stable soil food web, fosthiazate application induced primarily short-term functional responses without substantially altering overall community organization. Ecological indices, trophic composition, and multivariate analyses indicated relatively stable community structure together with comparatively balanced nutrient dynamics following treatment.

In contrast, the RKN orchard exhibited greater temporal variability in nematode community structure and ecological indices following fosthiazate application. This orchard remained dominated by lower trophic groups and showed declining trends in several nutrient parameters, suggesting reduced ecological buffering capacity under disturbance conditions. Multivariate analyses further indicated stronger associations between nematode community structure and physicochemical constraints, particularly soil pH.

Overall, these findings highlight that ecological responses to chemical disturbance are shaped by pre-existing soil conditions, including nematode infestation history and baseline food web structure.

The study emphasizes the importance of considering initial soil ecological status when evaluating the effects of nematicides and developing sustainable soil management strategies in perennial orchard systems.

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Author contributions

All authors were involved in the development and execution of the study, including conceptualization and research design, data analysis and interpretation, and methodological planning. All authors contributed to drafting the manuscript, as well as revising and critically reviewing its content. The final version of the manuscript was reviewed and approved by all authors.

Conflicts of interest

The authors declare no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used ChatGPT to improve language clarity and readability. The authors carefully reviewed and edited the content and take full responsibility for the final version of the manuscript.

References

[1] S. Z. Hussain, B. Naseer, T. Qadri, T. Fatima, and T. A. Bhat, "Guava (*Psidium guajava* L.)-Morphology, taxonomy, composition and health benefits," in *Fruits Grown in Highland Regions of the Himalayas,* Cham, Switzerland: Springe International Publishing, 2021, pp. 213–245, doi: 10.1007/978-3-030-75502-7_20.

[2] M. Kumar et al., "Guava (Psidium guajava L.) leaves: Nutritional composition, phytochemical profile, and health-promoting bioactivities," *Foods*, vol. 10, no. 4, Art. no. 752, Apr. 2021, doi: 10.3390/foods10040752.

[3] S. P. Singh, "Guava (*Psidium guajava* L.)," in *Postharvest Biology and Technology of Tropical and Subtropical Fruits*, vol. 3,

M. Yahia, Ed. Sawston, UK: Woodhead Publishing, 2011, pp. 213–246. doi: 10.15 33/9780857092885.213.
[4] D. P. Semwal et al., "Diversity distribution analysis of guava (Psidium guajava L.) populations in cultivated and wild habitats in the mid-hills of Uttarakhand, India," *Agriculture*, vol. 14, no. 4, Art. no. 575, Apr. 2024, doi: 10.3390/agriculture14040575.
[5] E. Arévalo-Marín et al., "The taming of Psidium guajava: Natural and cultural history of a neotropical fruit," *Frontiers in Plant Science*, vol. 12, Art. no. 714763, Sep. 2021, doi: 10.338 9/fpls.2021.714763.
[6] D. G. Omayio, G. O. Abong', M. W. Okoth, C. K. Gachuiri, and A. W. Mwang'ombe, "Trends and constraints in guava (*Psidium guajava* L.) production, utilization, processing and preservation in Kenya," *International Journal of Fruit Science*, vol. 20, no. 3, pp. 213–245, Jul. 2020. doi: 10.1080/15538362. 2020. 1791304.
[7] Thai Customs Department, "Statistics report," 2025. [Online]. Available:https://www.customs.go.th (accessed Dec. 1, 2025).
[8] A. Mandal, B. Sarkar, S. Mandal, M. Vithanage, A. K. Patra, and M. C. Manna, "Impact of agrochemicals on soil health," in *Agrochemicals Detection*, *Treatment and Remediation*, M. N. V. Prasad, Ed. Oxford, UK: Butterworth-Heinemann, 2020, ch. 7, pp. 161–187. doi: 10.1016/B978-0-08-1030 17-2.00007-6.
[9] J. Chen et al., "Comparative assessment of novel nematicide trifluen-furonate and fosthiazate on soil ecosystem: from microbial community structure to KEGG functional pathways," *Journal of Environmental Sciences*, vol. 163, pp. 209-419, May 2026, doi: 10.1016/ j.jes.2025. 05.033.
[10] N. Ntalli, Z. Adamski, M. Doula, and N. Monokrousos, "Nematicidal amendments and soil remediation," *Plants*, vol. 9, no. 4, Apr. 2020, doi: 10.3390/ plants9040429.
[11] J. W. Doran and M. R. Zeiss, "Soil health and sustainability: managing the biotic component of soil quality," *Applied Soil Ecology*, vol. 15, no. 1, pp. 3-11, Aug. 2000, doi: 10.1016/S0 929-1393(00)00067-6.
[12] Q. Lu, T. Liu, N. Wang, Z. Dou, K. Wang and Y. Zuo, "A review of soil nematodes as biological indicators for the assessment of soil health," *Frontiers of Agricultural Science and Engineering*, vol. 7, no. 3, pp. 275-281, Mar. 2020, doi: 10.15302/J-FASE-2020327.
[13] D. Gao, F. Wang, J. Li, S. Yu, Z. Li, and J. Zhao, "Soil nematode communities as indicators of soil health in different land use types in tropical area," *Nematology*, vol. 22, no. 6, pp. 595-610, Jul. 2020, doi: 10.1163/ 15685411-00003325.
[14] S. E. Laasli, F. Mokrini, R. Lahlali, T. Wuletaw, T. Paulitz, and A. A. Dababat, "Biodiversity of nematode communities associated with wheat (*Triticum aestivum* L.) in southern Morocco and their contribution as soil health bioindicators," *Diversity*, vol. 14, no. 3, Art. no. 194, Mar. 2022, doi: 10.3390/ d14030194.
[15] C. Boonrin, N. Beesa, K. Jindapunnapat, A. Sasnarukkit, P. J. Chen, and B. Chinnasri, "Morphological and Molecular Identification of *Meloidogyne enterolobii* Populations from Different Chili-Cultivated Areas in Ubon Ratchathani Province, Thailand," *Trends in Sciences*, vol. 21, no. 8, Art. no. 7816, Jun. 2024, doi: 10.48048/tis. 2024.7816.
[16] N. Beesa, N. Kuncharoen, T. Dethoup, K. Jindapunnapat, A. Sasnarukkit, and B. Chinnasri, "Prevalence and Characterization of Plant-Parasitic Nematodes Existing in RD41 Rice Fields in Pathum Thani Province, Thailand, with Emphasis on *Hirschmanniella mucronata* and *Meloidogyne graminicola*," *Trends in Sciences*, vol. 21, no. 12, Art. no. 8952, Oct. 2024, doi: 10.48048/ tis.2024.8952.
[17] I. R. G. Gondo et al., "Temporal dynamics of guava root-knot nematode under the effect of different management methods," *Crop Protection*, vol. 188, Art. no. 107012, Feb. 2025, doi: 10.1016/ j.cropro.2024.1 07012.
[18] M. A. Elsaedy, K. A. Osman, and A. M. Younis, "Characterization and management of crown gall bacterium and root-knot nematode as a complex disease infecting guava plants," *Discovery Plants*, vol. 2, Art. no. 326, 2025, doi: 10.1007/s44372-025-004 19-6.

[19] K. Uesugi and Y. Tateishi, "Effect of nematicides for ornamental trees on Pratylenchus penetrans eggs," *Japanese Journal of Nematology*, vol. 55, no. 1, May 2025. doi: 10.3725/jjn.55.1.
[20] E. K. Kandil, M. M. Nofel, A. M. Abdelaziz, M. M. Mansour, and M. S. Attia, "Effectual role of plant growth-promoting fungi and fosthiazate in controlling tomato root-knot nematode infection: *In vivo* and *in vitro* studies," *Physiological and Molecular Plant Pathology*, vol. 134, Art. no. 102463, Dec. 2024, doi: 10.1016/j.pmpp.2024.102463.
[21] B. Chinnasri et al., "Efficacy of fosthiazate (Nemathorin 10 % GR) in managing *Meloidogyne enterolobii* in chili crop in Thailand," *Crop Protection*, vol. 199, Art. no. 107425, Jan. 2026, doi: 10.1016/j. cropro.2025. 107 425.
[22] D. Cheng, S. Lin, G. Liu, Y. Zhou, and Z. Zhang, "Residue and distribution of fosthiazate in cucumber (*Cucumis sativus* L.) and dietary intake risk assessment for various populations," *International Journal of Environmental Analytical Chemistry*, vol. 103, no. 18, pp. 6804–6815, Dec. 2023, doi: 10.1080/0306731 9.2021. 1962318.
[23] M. Kawanobe, K. Toyota, T. Fujita, and D. Hatta, "Evaluation of Nematicidal Activity of Fluensulfone against Non-Target Free-Living Nematodes under Field Conditions," *Agronomy*, vol. 9, no. 12, Art. no. 853, Dec. 2019, doi: 10.3390/agrono my9120853.
[24] M. Touray et al., "The impact of chemical nematicides on entomopathogenic nematode survival and infectivity," *Journal of Nematology*, vol. 53, pp. e2021-49, Jun. 2021, doi: 10.21307/jofnem-2021-049.
[25] Y. Liu et al., "Organophosphorus nematicide potentiated nematicidal effect by changing rhizosphere bacterial and fungal communities," *Rhizosphere*, vol. 31, Art. no. 100936, Sep. 2024, doi: 10.1016/j.rhisph. 2024.100936.
[26] S. K. Pothula, G. Phillips, and E. C. Bernard, "Increasing levels of physical disturbance affect soil nematode community composition in a previously undisturbed ecosystem," *Journal of Nematology*, vol. 54, no. 1, Art. no. 20220022, Jun. 2022, doi: 10.2478/jofnem-2022-0022.
[27] H. Ferris, T. Bongers, and R. G. M. de Goede, "A framework for soil food web diagnostics: extension of the nematode faunal analysis concept," *Applied Soil Ecology*, vol. 18, no. 1, pp. 13-29, Sep. 2001, doi: 10.1016/S0929-1393(01)00152-4.
[28] C. S. Holling, "Resilience and stability of ecological systems," in *Foundations of Socio-Environmental Research*: *Legacy Readings with Commentaries*, W. R. Burnside, S. Pulver, K. J. Fiorella, M. L. Avolio, and S. M. Alexander, Eds. Cambridge, UK: Cambridge University Press, 2023, pp. 460–482.
[29] K. Jindapunnapat and B. Chinnasri, "Development of the molecular markers for species identification of root-knot nematode infesting guava in Thailand," M.S. thesis, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand, 2012, doi: 10.14457/ KU. the.2012.13.
[30] G. Baermann, "Eine einfache Methode zur Auffindung von Ancylostomum (Nematoden) Larven in Erdproben," *Geneeskundig Tijdschrift voor Nederlandsch-Indië*, vol. 57, pp. 131-137, 1917.
[31] J. W. Seinhorst, "A rapid method for the transfer of nematodes from fixative to anhydrous glycerin," *Nematologica,* vol. 4, no. 1, pp. 67-69, Jan. 1959, doi: 10.1163/ 187529 259X00381.
[32] T. Bongers, "The maturity index: an ecological measure of environmental disturbance based on nematode species composition," *Oecologia*, vol. 83, no. 1, pp. 14-19, May 1990, doi: 10.1007/ BF00324627.
[33] B. Sieriebriennikov, H. Ferris, and R. G. M. de Goede, "NINJA: An automated calculation system for nematode-based biological monitoring," *European Journal of Soil Biology*, vol. 61, pp. 90-93, Mar.-Apr. 2014, doi: 10.1016/ j.ejsobi. 2014. 02.004.
[34] A. Walkley and I. A. Black, "An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method," *Soil Science*, vol. 37, no. 1, pp. 29–38, Jan. 1934, doi: 10.109 7/00010694-193401000-00003.
[35] V. P. Gautam, S. Mishra, and H. Ahmed, "Comparison of total nitrogen estimation by Kjeldahl method and CHNS analyzer in dry tropical grassland," *International Journal of*

Plant and Environment, vol. 9, no. 2, pp. 180–182, Aug. 2023, doi: 10.18811/ijpen.v9i02.13.

[36] L. V. Thuc et al., "Effects of nitrogen fertilization and nitrogen fixing endophytic bacteria supplementation on soil fertility, N uptake, growth, and yield of sesame(*Sesamumindicum* L.) cultivated on alluvial soil in dykes," *Applied and Environmental Soil Science*, vol. 2022, Art. no. 1972585, 2022, doi: 10.1155/ 2022/1972585.

[37] B. van Raij, J. A. Quaggio, and N. M. da Silva, "Extraction of phosphorus, potassium, calcium, and magnesium from soils by an ion-exchange resin procedure," *Communications in Soil Science and Plant Analysis*, vol. 17, no. 5, pp. 547-566, May 1986.

[38] G. J. Bouyoucos, "Hydrometer method improved for making particle size analyses of soils," *Agronomy Journal*, vol. 54, no. 5, pp. 464–465, Sep. 1962. doi: 10.2134/agronj1962. 00021962 005400050028x.

[39] K. H. Wang, R. McSorley, and N. Kokalis-Burelle, "Effects of Cover Cropping, Solarization, and Soil Fumigation on Nematode Communities," *Plant and Soil*, vol. 286, no. 1-2, pp. 229–243, Sep. 2006. doi: 10.1007/s11104-006-9040-4.

[40] H. Wang et al., "Fosthiazate inhibits root-knot disease and alters rhizosphere microbiome of Cucumis melo var. saccharinus," *Frontiers in Microbiology*, vol. 13, Art. no. 1084010, Jan. 2023, doi: 10.3389/fmicb.2022. 1084010.

[41] S. Na, H. L. Hayden, J. Z. He, Z. Y. He, R. Ghaderi, L. Bi, and H. W. Hu, "Bacterivorous nematodes drive ammonification and bacterial community growth in a strongly acidic soil," *Journal of Sustainable Agriculture and Environment*, vol. 4, no. 1, Mar. 2025, doi: 10.1002/sae2.70057.

[42] H. Ferris, S. Sánchez-Moreno, and E. B. Brennan, "Structure, functions and interguild relationships of the soil nematode assemblage in organic vegetable production," *Applied Soil Ecology*, vol. 61, pp. 16–25, Oct. 2012, doi: 10.1016/j.apsoil.20 12.04.006.

[43] J. Trap, M. Bonkowski, C. Plassard, C. Villenave, and D. L. Cluzeau, "Ecological importance of soil bacterivores for ecosystem functions," *Plant and Soil*, vol. 398, pp. 1–24, Jan. 2016, doi: 10.1007/ s11104-015-2671-6.

[44] J. Zhao, S. Li, X. He, L. Liu, and K. Wang, "The soil biota composition along a progressive succession of secondary vegetation in a karst area," *PLOS ONE*, vol. 9, no. 11, Nov. 2014, doi: 10.1371/journal. pone.01 12436.

[45] M. Zhang et al., "Effects of alpine meadow degradation on soil nematode diversity and community composition on the Qinghai-Tibet Plateau," *Ecological Indicators*, vol. 178, Art. no. 114106, Sep. 2025, doi: 10.1016/j.ecolind. 2025. 114106.

[46] F. T. de Vries et al., "Soil food web properties explain ecosystem services across European land use systems," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 110, no. 35, pp. 14296–14301, Aug. 2013, doi: 10.1073/pnas.1305198110.