Multidisciplinary Collaborative Journal
ISSN: 3073-1356

DOSO EDITORIAL CIENTÍFICA

Article

Soil Nematode Communities as Environmental Indicators in Plantations and Natural Tropical Forests of Ecuador

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https://doi.org/10.70881/mcj/v3/n4/86

Citation: Vera Aviles, D., Mendoza Hernández, C., & Burgos Chiriguay, E. (2025). Las comunidades de nematodos del suelo como indicadores medioambientales en plantaciones y bosques tropicales naturales de Ecuador. *Multidisciplinary Collaborative Journal*, *3*(4), 17-32. https://doi.org/10.70881/mcj/v3/n4/86

Received: 15/04/2025
Revised: 25/09/2025
Accepted: 30/09/2025
Published: 07/10/2025

Abstract: Soil nematodes are fundamental components of terrestrial ecosystems and serve as sensitive bioindicators of soil health, yet their diversity and ecological functions in tropical forests remain underexplored. This study characterized nematode communities in natural forests and teak (*Tectona grandis*) plantations at two localities in Ecuador (La María and La Represa), evaluating abundance, diversity, and ecological indices. A total of 14,250 individuals were identified, with Meloidogyne (43.16%) and Pratylenchus (25.61%) as dominant families, followed by Mononchus (12.28%), while Dorylaimus and Rhabditis represented lower proportions (9.47%). Diversity indices indicated medium to high diversity (Shannon: 2.52–2.67) and high evenness, particularly in natural forests. The maturity index (MI) highlighted significant differences between systems, with higher values in natural forests (3.02–3.4) suggesting greater stability and lower disturbance compared to plantations (3.0–3.2), which reflected the prevalence of colonizer taxa. Despite higher abundance in plantations, natural forests supported more balanced trophic structures and greater ecological stability. These findings are consistent with global evidence that land-use intensification reduces soil biodiversity and trophic complexity. Overall, nematode communities in Ecuadorian tropical soils provide robust indicators of ecological integrity, emphasizing the importance of conserving natural forests and integrating nematode-based metrics into sustainable land management and restoration strategies in tropical regions.

Keywords: Soil nematodes, biodiversity, teak plantations, natural forests, bioindicators

Resumen: Los nematodos del suelo son componentes fundamentales de los ecosistemas terrestres y sirven como bioindicadores sensibles de la salud del suelo, pero su diversidad y funciones ecológicas en los bosques tropicales siguen sin estar suficientemente estudiadas. Este estudio caracterizó las comunidades de nematodos en bosques naturales y plantaciones de teca (*Tectona grandis*) en dos localidades de Ecuador (La María y La Represa), evaluando la abundancia, la diversidad y los índices ecológicos. Se identificaron un total de 14 250 individuos, siendo Meloidogyne (43,16 %) y Pratylenchus (25,61 %) las familias dominantes, seguidas de Mononchus (12,28 %), mientras que Dorylaimus y Rhabditis representaron proporciones menores (9,47 %). Los índices de diversidad indicaron una diversidad media-alta (Shannon: 2,52-2,67) y una uniformidad alta, especialmente en los bosques naturales. El índice de madurez (IM) puso de relieve diferencias significativas entre los sistemas, con valores más altos en los bosques naturales (3,02-3,4), lo que sugiere una mayor estabilidad y menos perturbaciones en comparación con las plantaciones (3,0-3,2), lo que reflejaba la prevalencia de taxones colonizadores. A pesar de la mayor abundancia en las plantaciones, los bosques naturales presentaban estructuras tróficas más equilibradas y una mayor estabilidad ecológica. Estos resultados concuerdan con las pruebas globales de que la intensificación del uso de la tierra reduce la biodiversidad del suelo y la complejidad trófica. En general, las comunidades de nematodos en los suelos tropicales ecuatorianos proporcionan indicadores sólidos de la integridad ecológica, lo que pone de relieve la importancia de conservar los bosques naturales e integrar métricas basadas en los nematodos en las estrategias de gestión y restauración sostenibles de la tierra en las regiones tropicales

Palabras clave: Nematodos del suelo, biodiversidad, plantaciones de teca, bosques naturales, bioindicadores

1. INTRODUCTION

Soils represent one of the most biologically diverse habitats on Earth, harboring nearly a quarter of global biodiversity and sustaining processes that are indispensable for human life (Robinson et al., 2024; Voroney et al., 2024; Wall et al., 2015). They provide the foundation for 95% of global food production and support the provision of fibres, fuels, and pharmaceuticals, yet their biological complexity remains critically undervalued (Aransiola et al., 2024; Fatima et al., 2024; Fausak et al., 2024). Among the vast array of organisms inhabiting soils, nematodes stand out due to their ubiquity, abundance, and functional diversity, positioning them as central drivers of ecosystem dynamics (Tu et al., 2024a; Wilschut & Geisen, 2021; Zhang et al., 2024).

Nematodes participate in virtually all soil processes, contributing to nutrient cycling, decomposition, and energy transfer within food webs (Li et al., 2024; Wang et al., 2024; Zhu et al., 2023). They are responsible for up to 30% of nitrogen mineralization in soils, thus directly influencing plant productivity and ecosystem fertility (Zhu et al., 2023). Their trophic diversity is remarkable, encompassing bacterivores, fungivores, phytoparasites, predators, and omnivores, all of which maintain the balance of soil ecosystems and regulate interactions between plants, microbes, and higher trophic levels. Because of these attributes, nematodes are not only critical for sustaining soil functions but also represent valuable indicators of environmental quality (Furmanczyk et al., 2025; Lazarova et al., 2021; Xing et al., 2022).

The development of ecological indices based on nematode communities, such as the maturity index and food web indices, has provided robust tools to evaluate soil health and ecosystem stability. These indices integrate taxonomic composition with functional traits, revealing both the capacity of soils to sustain nutrient cycling and their resilience to disturbances (Ghaderi et al., 2025; Gonzalez et al., 2025; Pires et al., 2023). Changes in nematode communities are highly sensitive to anthropogenic pressures, including deforestation, intensive agriculture, and the application of agrochemicals, making them reliable sentinels of environmental change (Lehun et al., 2023; Pires et al., 2023; Zheng et al., 2024)

In tropical ecosystems, where biodiversity is unparalleled yet under severe pressure, the role of nematodes as bioindicators gains particular relevance (Afzal & Ahmad, 2024; Shao et al., 2023). Ecuador, situated within one of the most biodiverse regions of the planet, faces rapid land-use changes driven by agricultural expansion, logging, and infrastructure development (López-Tobar et al., 2024; Noh et al., 2022). These processes threaten forest integrity and alter soil ecological functions. Understanding how nematode communities respond across gradients of land use is therefore crucial for informing conservation strategies and sustainable management of tropical soils (Biswal, 2022; Kleemann et al., 2022; Koo et al., 2024; Semprucci et al., 2025).

In this context, the present study aims to characterize nematode communities in plantations, secondary forests, and natural tropical forests in Ecuador. By assessing their density, diversity, and functional structure, and by applying ecological indices that capture soil condition and food web dynamics, this research seeks to establish the extent to which nematodes can be used as environmental indicators. This approach not only contributes to the understanding of soil biodiversity in tropical ecosystems but also provides evidence to guide policies and practices that reconcile forest conservation with productive land use.

2. METHODOLOGY

2.1 Study areas

The study was conducted in two sites of the State Technical University of Quevedo: La María and La Represa, during December at the onset of the rainy season. Edaphic nematode communities were sampled under two land covers: teak (*Tectona grandis* L.f.) plantations (PFT) and natural forests (BN). The teak stand in La Represa is about 20 years old, while in La María it is approximately eight years old, enabling comparison between plantations of different ages. Natural forests served as reference systems to assess the ecological integrity of nematode communities. These areas integrate high species diversity, complex canopy structure, regeneration dynamics, and flora–fauna interactions, while providing key ecosystem services such as climate regulation, soil stabilization, and biodiversity conservation. Understanding these attributes is essential for developing sustainable management strategies in tropical soils.

Within La Represa natural forest, diverse tree species were identified, including *Roseodendron donnell-smithii* (Guayacán Blanco), *Cordia alliodora* (Laurel), *Centrolobium ochroxylum* (Amarillo lagarto), *Cecropia peltata* (Guarumo), *Triplaris cumingiana* (Fernán Sánchez), *Erythrina poeppigiana* (Bombón), *Cedrela odorata* (Cedar), and *Maclura tinctoria* (Moral fino). On the La María campus, characteristic species were recorded such as *Pseudobombax millei* (Beldaco), *Erythrina poeppigiana* (Bombón), *Mangifera indica* (Mango), *Erythrina velutina* (Palo prieto), *Mespilus germanica* (Níspero), *Ficus* sp. (Higuerón) and *Cecropia peltata* (Guarumo).

For soil sampling, two 5 × 5 m (25 m²) plots were established at each site, one within the teak plantation and one in the native forest, resulting in four plots in total. In each plot, four rhizospheric soil samples were collected to characterize nematode communities and assess their ecological dynamics under contrasting land covers.

2.2 Sample collection and analysis

Soil nematode communities were sampled following standardized protocols (Vélez & Guzmán, 2022). Four 5 × 5 m plots (25 m²) were established, from which four composite samples were obtained. At each sampling point, three 20 × 20 cm quadrats were excavated to a depth of 20 cm, and the subsamples were homogenized and stored in labelled plastic bags indicating site and replicate.

Nematodes were extracted using the modified Baermann funnel technique (Cesarz et al., 2019). Soil samples were sieved at 4 mm to remove coarse particles, and 250 g of homogenized soil were processed by capillary wetting, allowing active nematodes to migrate into the water phase. After 48 h, the nematode suspensions were recovered and sequentially filtered through 60, 140 and 500 mesh sieves. The final concentrate was examined under a microscope for nematode identification and total counts.

Diversity was quantified using the Shannon–Wiener index (Ht = –Σ ti log2 ti), which integrates taxon richness and relative abundance. Evenness was calculated as Et = Ht / Htmax, where Htmax = log2 (number of taxa), providing a standardized measure of equity across families. To assess successional status, the maturity index (MI) was computed (Bongers, 1990) using MI = Σ vi pi, where vi is the c–p value of taxon i and pi its proportional abundance, excluding phytophagous groups. All ecological indices were calculated using the NINJA software (Sieriebriennikov et al., 2014), which integrates nematode-based indicators for soil quality assessment.

3. RESULTS

3.1 Abundance and Composition of Soil Nematode Communities

A total of 14,250 nematodes were identified across the two localities and land covers (Table 1). The genus Meloidogyne dominated the assemblages, representing 43.16% of individuals (6,150), followed by Pratylenchus with 25.61% (3,650). Predatory taxa such as Mononchus accounted for 12.28% (1,750), while Dorylaimus and Rhabditis exhibited the lowest abundances, each representing 9.47% of the community (1,350 individuals).

When comparing land covers, teak plantations supported a higher total abundance (8,400 individuals) compared with natural forests (5,850) (Figure 1). This trend was consistent across both study sites, with Meloidogyne and Pratylenchus showing a marked increase in plantations, suggesting that land-use change favors the proliferation of plant-parasitic genera. Conversely, genera associated with free-living and predatory functions (Mononchus, Dorylaimus, Rhabditis) were relatively more balanced between plantations and natural forests, though their overall representation remained lower.

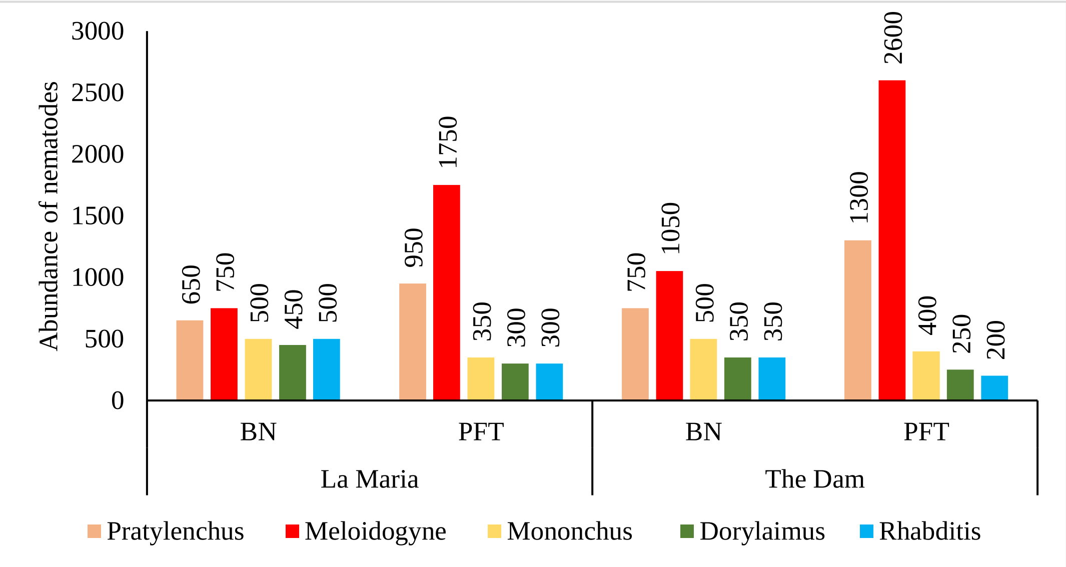
Table 1.

Abundance of nematodes at genus level in two localities and two study areas.

Gender	**Mocache**		**Quevedo**		**Total**	**Percentage (%)**
	Natural Forest	**Teak plantation**	**Natural Forest**	**Teak plantation**		
Pratylenchus	650	950	750	1300	3650	25,61
Meloidogyne	750	1750	1050	2600	6150	43,16
Mononchus	500	350	500	400	1750	12,28
Dorylaimus	450	300	350	250	1350	9,47
Rhabditis	500	300	350	200	1350	9,47
Total	**2850**	**3650**	**3000**	**4750**	**14250**	**100**

Figure 1.

Abundance of nematodes at genus level in two localities and two forest systems.



3.2 Ecological diversity indices of nematode communities

Biological The nematode communities identified in both forest systems and teak plantations were characterized through ecological indices that describe their diversity and distribution patterns (Table 2). Simpson's index (1-D) ranged from 0.90 to 0.92 across the genera, evidencing a high diversity and the absence of strong dominance by a single taxon. The Shannon index (H) varied between 2.52 and 2.67, which corresponds to intermediate levels of community diversity, suggesting the coexistence of several genera with balanced proportions. Evenness (e^H/S) values were consistently high, ranging from 0.77 to 0.90, indicating that the abundance of individuals was relatively evenly distributed among the different genera. Similarly, the equitability index (J) showed values between 0.91 and 0.96, reinforcing the interpretation that nematode communities exhibit a uniform distribution without extreme predominance of any genus.

Table 2.

Biodiversity index values according to Genus.

Diversity indices	Pratylenchus	Meloidogyne	Mononchus	Dorylaimus	Rhabditis
N° of individuals	3650	6150	1750	1350	1350
Simpson_1-D	0,9171	0,9011	0,9246	0,9143	0,9088
Shannon_H	2,632	2,523	2,673	2,615	2,583
Evenness_e^H/S	0,869	0,7793	0,9055	0,8538	0,8269
Equitability_J	0,9494	0,9101	0,9642	0,943	0,9315

3.3 Ecological diversity as a function of forest systems

The analysis of ecological indices revealed that natural forests exhibited higher diversity values compared to teak plantations, regardless of the locality (Table 3). In La María, the natural forest showed higher Simpson and Shannon indices than La Represa, despite the latter presenting a greater number of individuals. This indicates that a larger population size does not necessarily reflect higher ecological diversity, but rather the balance in the distribution of genera.

Table 3.

Biodiversity index values as a function of ecological systems.

Diversity indices	Mocache		Quevedo	
	BN	**PFT**	**BN**	**PFT**
Number of individuals	2850	3650	3000	4750
Simpson_1-D	0,793	0,680	0,760	0,614

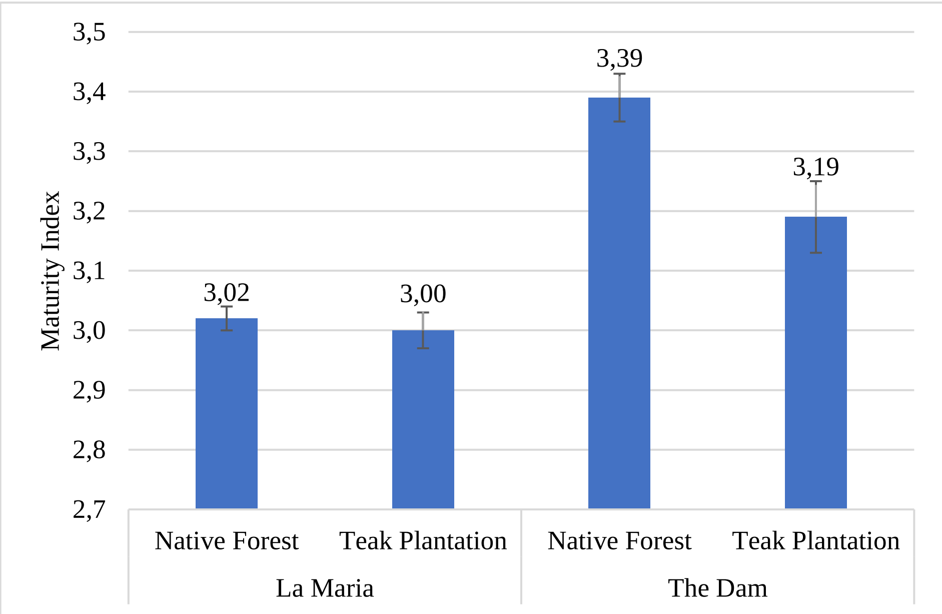
Shannon_H	1,591	1,339	1,515	1,182
Evenness_e^H/S	0,982	0,763	0,910	0,652
Equitability_J	0,989	0,832	0,941	0,734

3.4. Maturity index of nematode communities

The maturity index (MI) provided evidence of differences in the conservation status of the evaluated ecosystems (Figure 2). In La María, the native forest presented a value of 3.02, slightly higher than the teak plantation, which reached 3.00. Although the difference is small, it suggests that the native forest maintains marginally more stable nematode communities compared to the plantation. In contrast, La Represa exhibited clearer distinctions. The native forest recorded the highest MI value (3.39), while the teak plantation obtained 3.19. These results indicate that natural forests harbor nematode communities with greater ecological stability and reduced signs of disturbance. Plantations, despite supporting high abundances, reflect a lower successional stage, associated with simplified trophic structures and reduced ecological resilience.

Figure 2.

Values of the Maturity Indexes (MI).



3.5 To taxonomically describe the nematode general present in the study localities.

Soil analysis in the studied ecosystems revealed the presence of five nematode genera: Pratylenchus, Meloidogyne, Mononchus, Dorylaimus and Rhabditis. These genera were consistently found across both natural forests and teak plantations, as well as in the two study localities, La María and La Represa (Table 4). Their ubiquity suggests that these genera constitute a core component of soil nematode communities in tropical ecosystems of coastal Ecuador.

The functional traits of these genera reflected distinct feeding strategies that shape belowground trophic networks. Pratylenchus and Meloidogyne were classified as herbivores, highlighting their role as potential root parasites with direct implications for plant health and productivity. By contrast, Mononchus functioned as a predator, contributing to the regulation of smaller nematodes and other microfauna. Dorylaimus exhibited an omnivorous feeding habit, which points to its ecological versatility in exploiting diverse resources. Finally, Rhabditis was bacteriophagous, directly associated with the decomposition of organic matter and microbial turnover (Table 5).

Table 4.

Nematode genus in two localities and two study areas.

Location	**Mocache**	**Quevedo**		
Genus	**Natural Forest**	**Plantation (*T. grandis*)**	**Natural Forest**	**Plantation (*T. grandis*)**
Pratylenchus	X	X	X	X
Meloidogyne	X	X	X	X
Mononchus	X	X	X	X
Dorylaimus	X	X	X	X
Rhabditis	X	X	X	X

Table 5.

Habits of nematode genus in two localities and two study areas

Genus	**Eating Habit**			
	Herbivore	**Predator**	**Omnivore**	**Bacteriophage**
Pratylenchus	X			
Meloidogyne	X			

Mononchus		X		
Dorylaimus			X	
Rhabditis				X

4. DISCUSSION

Nematodes, as soil invertebrates, play essential roles in decomposition, nutrient cycling, and energy flow, making them reliable bioindicators of ecosystem functioning (Lu et al., 2020; Neher, 2010). In this study, five dominant families (Meloidogyne, Pratylenchus, Mononchus, Dorylaimus, and Rhabditis) were identified across natural forests and teak plantations in Ecuador. Their presence in both ecological systems reflects the adaptability of nematode taxa to different soil environments, a trend also observed in global assessments where nematodes persist across gradients of disturbance and vegetation cover (Van Den Hoogen et al., 2020).

The predominance of herbivorous nematodes (Meloidogyne, Pratylenchus) is consistent with their known capacity to exploit monoculture systems, often increasing under simplified vegetation structures (Habteweld et al., 2024; Thougnon Islas et al., 2024). However, our results contrast with studies in other tropical forests where bacterivorous and omnivorous groups dominate, particularly under higher organic matter availability and microbial activity. These discrepancies may be explained by differences in soil fertility, microclimatic conditions, and management history of each system (Pires et al., 2023; Shao et al., 2023; Suman Ramteke et al., 2024).

Biodiversity indices provided further insights. Shannon and Simpson values indicated medium to high diversity across sites, with greater evenness in natural forests than in plantations. Similar patterns have been reported in Amazonian and Andean ecosystems, where complex canopy and litter inputs sustain diverse nematode communities, while managed systems tend to reduce trophic complexity (Krashevska et al., 2019; Tu et al., 2024b; Wen et al., 2025). Differences between “La María” and “La Represa” likely reflect site-specific edaphic factors and management intensity, underscoring the sensitivity of nematodes to local ecological conditions.

The maturity index highlighted clear contrasts between forest systems and plantations. Higher MI values in natural forests suggest communities dominated by K-strategist taxa typical of stable ecosystems, whereas plantations showed lower values associated with opportunistic colonizers. Comparable results have been documented in tropical and temperate systems, where forestry practices alter nematode guilds through changes in organic inputs and disturbance regimes (Čerevková et al., 2021; Sánchez-Moreno & Talavera, 2013).

Overall, these findings reinforce the importance of nematode communities as integrative indicators of soil health. By comparing local results with global evidence, it becomes evident that forest conservation supports functional diversity and ecosystem stability, while monocultures simplify food webs and increase vulnerability. Incorporating nematode-based metrics into soil monitoring frameworks could enhance sustainable land management strategies in tropical regions.

5. CONCLUSION

This study demonstrates that soil nematode communities are sensitive and robust indicators of ecosystem condition in tropical environments of Ecuador. The dominance of phytoparasitic groups such as Meloidogyne and Pratylenchus highlights the persistent pressure on root systems, while the presence of predatory and bacterivorous taxa reflects the functional heterogeneity required for soil resilience. Diversity and maturity indices confirmed that natural forests sustain more stable and balanced communities compared to teak plantations, underscoring the ecological costs of land-use simplification.

Overall, the comparative analysis between natural and managed systems reveals that nematode-based metrics provide a powerful tool to monitor soil health, evaluate ecological maturity, and detect early signs of disturbance. These findings reinforce the importance of conserving native forests to maintain trophic complexity and functional diversity, while also suggesting that plantation management should integrate biological indicators to achieve sustainability. Nematode community analysis therefore offers not only ecological insight but also practical applications for restoration and land-use planning in tropical regions.

Authors' Contributions: Conceptualization, D.V.A., C.M.H., and E.B.C.; methodology, D.V.A., C.M.H., and E.B.C.; investigation, D.V.A., C.M.H., and E.B.C.; validation, C.M.H.; formal analysis, D.V.A.; resources, D.V.A.; data curation, D.V.A., C.M.H., and E.B.C.; writing—original draft preparation, D.V.A.; writing—review and editing, D.V.A., C.M.H., and E.B.C.; visualization, D.V.A.; supervision, C.M.H.; project administration, D.V.A.; funding acquisition, D.V.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors sincerely thank the Quevedo State Technical University and the Faculty of Agricultural and Forestry Sciences.

Data Availability Statement: The data are available upon reasonable request from the corresponding author: dvera@uteq.edu.ec

Conflict of Interest: The authors declare no conflict of interest.

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