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The Vectorial Role Of The Earthworm In Plant-Parasitic Nematode Dispersal

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Abstract- ***Plant-parasitic nematodes (PPNs) pose a significant threat to global agriculture, resulting in substantial annual crop yield losses. Although largely immobile in soil, PPNs exploit earthworms as biological vectors for dispersal across farmlands. This study investigated the complex interactions between earthworms and PPNs, specifically examining how earthworm burrowing, feeding, and casting behavior facilitates or impedes nematode migration. Specimens of Lumbricus terrestris were extracted from three soil types — swampy, semi-dry, and dry — within the Kolo Creek area of Ogbia Local Government Area, Bayelsa State, Nigeria. Following dissection, gut contents were analyzed using the Baermann funnel method for nematode identification and quantification. Results indicated the presence of PPNs across all soil environments: 23 individuals (51%) from swampy land, 17 (37%) from semi-dry land, and 5 (11%) from dry land. A one-way Analysis of Variance (ANOVA) confirmed that these differences were statistically significant ($P < 0.05$), indicating that soil moisture significantly influences earthworm vectorial capacity. These findings underscore the role of earthworms as vectors in dispersing economically important PPNs. An understanding of this relationship is vital for developing sustainable agricultural management strategies that effectively control PPN infestations while preserving the beneficial ecological services provided by earthworms.***

Keywords: Earthworm, Plant-Parasitic Nematodes, Vectorial Capacity, Dispersal, Soil Ecology, Infestation

I. INTRODUCTION

Earthworms are critical components of terrestrial ecosystems, performing vital functions such as converting organic waste into plant-available nutrients and releasing abundant soil microorganisms that support ecosystem health without introducing pollutants (Susan & Sulhar, 2020). As members of the phylum Annelida, earthworms constitute a large and ecologically diverse group comprising over 6,000 described species, each adapted to distinct ecological niches with varying life-history strategies (Capa & Hutchings, 2021). They are broadly categorized into three functional groups — epigeic, endogeic, and anecic — based primarily on their feeding habits and burrowing behavior (Ahmed & Al-Mutairi, 2022). Owing to their large body size and broad dietary habits, earthworms can inadvertently ingest a diverse array of microorganisms, including fungi, viruses, and nematodes, thus assuming the ecological role of vectors (Hoeffner et al., 2018).

Earthworms are recognized vectors for several pathogenic agents capable of causing disease in both plants and animals. They have the capacity to ingest and retain pathogens such as fungi, viruses, and bacteria, subsequently excreting them into the surrounding environment and thereby contaminating soil and potentially infesting organisms that come into contact with earthworm bodies or their castings (Gudeta et al., 2023). Earthworms are also implicated in the transport and dissemination of plant pathogens, including Fusarium spp. and Pythium spp., as well as diseases such as potato wart disease (Zhao et al., 2025). Furthermore, their burrowing activity creates macropores that act as conduits, facilitating the more rapid movement of soil-borne pathogens to infection sites. Earthworms may additionally harbor animal parasites — including hookworms, roundworms, tapeworms, and Ascaris spp. — which are transmissible to animals upon ingestion (Xie et al., 2025).

Nematodes are one of the most abundant invertebrate groups in soil, with population densities ranging from 10^6 to 10^7 m^{-2} and biomass reaching up to 100 kg ha^{-1}. They exhibit remarkable ecological diversity, encompassing free-living bacterivores, fungivores, omnivores, and predatory species that regulate trophic chains in the soil, as well as parasitic species affecting both plants and animals (Zhu et al., 2024; Mendoza-de Gives, 2022). Given the small body size of PPNs, they

are inevitably ingested by earthworms in considerable numbers (Zheng et al., 2022). Although PPNs typically travel no more than one millimeter during their entire lifespan, earthworms facilitate their broader dispersal by excreting viable nematodes in coprolites deposited at new locations — a hitchhiking mechanism that substantially extends the spatial range of PPN infestations (Pulavarty et al., 2022; Vlaar et al., 2021). Crucially, PPN eggs and juvenile stages survive passage through the earthworm digestive tract without premature hatching or mortality, thus preserving their infective potential and further promoting dispersal (Packi et al., 2023).

Despite growing recognition of the earthworm the role as a mechanical vector, empirical investigations into the influence of edaphic factors — particularly soil moisture — on earthworm vectorial capacity remain limited. The present study therefore aimed to: (i) quantify PPNs recovered from the gut contents of L. terrestris collected across soil types with varying moisture levels; (ii) evaluate the influence of soil moisture on PPN recovery rates; and (iii) contextualize findings within established theoretical frameworks describing earthworm–pathogen interactions. The outcomes of this study have direct implications for the integrated management of soil-borne nematode pests in tropical agroecosystems.

II. MATERIALS AND METHODS

2.1 Study Site and Sample Collection

Earthworm specimens (*Lumbricus terrestris*) were collected from three distinct farmland types — swampy, semi-dry, and dry — located within the Kolo Creek area of Ogbia Local Government Area, Bayelsa State, Nigeria. Samples were extracted manually by digging to depths of 2 cm to 9 cm. Collected worms were carefully removed from their natural substrate and immediately transported to the laboratory under sterile conditions to prevent contamination.

2.2 Dissection and Gut Content Preservation

Upon arrival, earthworms were surface-sterilized and dissected under aseptic conditions. Gut contents were carefully excised and preserved below ambient room temperature to maintain sample integrity prior to analysis.

2.3 Nematode Extraction and Identification

Gut contents were placed in clean water and processed using the Baermann funnel method for nematode extraction. This technique exploits nematode motility to facilitate their active migration from gut tissue into the surrounding water. Apparatus was allowed to stand for 12 to 48 hours. Extracted nematodes were then observed and identified under a compound microscope, using established morphological keys for plant-parasitic nematode identification. Quantification was performed using a counting dish.

2.4 Statistical Analysis

Data obtained from nematode counts across the three soil environments were subjected to descriptive statistics to determine mean distributions and percentage contributions. To assess the statistical significance of variations in PPN recovery among soil types, a one-way Analysis of Variance (ANOVA) was employed, followed by a post-hoc Tukey’s Honestly Significant Difference (HSD) test at a significance level of $P < 0.05$. This analysis was used to determine whether moisture-related soil characteristics significantly influenced the vectorial capacity of *L. terrestris.*

III. THEORETICAL FRAMEWORK: MECHANISMS OF EARTHWORM–PATHOGEN INTERACTION

The theoretical framework of this study is grounded in the multidimensional interaction among earthworm biology, soil ecology, and the life cycle of PPNs. Rather than functioning as a conventional blood-feeding vector, the earthworm acts as a biogeochemical and physical agent that modifies the spatial and temporal dynamics of soil-borne pathogens. This study draws upon four primary models to explain the vectorial role of *Lumbricus terrestris.*

3.1 Gut Environment Model

The unique gut chemistry and associated microbial communities within the earthworm digestive tract determine whether ingested pathogens are destroyed, persist, or proliferate. The earthworm gut functions as a self-contained bioreactor with specific

physicochemical conditions — including pH and redox potential — and a distinct microbiome that significantly influences the fate of transiting microorganisms and pathogens. Aira and Domínguez (2025) reported that, despite overall reductions in microbial loads in earthworm casts, gut transit progressively increases the abundance of certain human bacterial pathogens, highlighting the selective nature of earthworm gut ecology.

3.2 Immune Response Model

Earthworms possess a robust innate immune system comprising antimicrobial peptides (AMPs) and coelomocytes, among other defense mechanisms. The effectiveness of these defenses against specific pathogens is a critical determinant of whether an earthworm acts as a competent vector or actively eliminates a pathogen. Kokhanyuk et al. (2022) demonstrated that earthworm immune cells share strongly conserved bacterial engulfment mechanisms with human immune cells, suggesting that pathogen-specific features — such as the robust outer cuticle of PPNs — may enable evasion of these innate defenses.

3.3 Bioaccumulation and Tissue-Binding Model

Bioaccumulation models (e.g., Belfroid et al., 1995) and associated kinetic frameworks estimate the accumulation of organic chemicals or heavy metals in earthworm tissues based on soil organic matter content and chemical properties. By extension, Li et al. (2024) demonstrated that infectious agents — such as prions — can bind to earthworm tissues and be retained as infectious material for extended periods, potentially rendering the worm itself a long-term source of environmental contamination.

3.4 Transmission Dynamics and Epidemiological Model

The vectorial importance of earthworms is increasingly incorporated into broader epidemiological models, particularly those developed for soil-transmitted helminths (STH). This model assesses how earthworm activity enhances the dispersal of STH by generating “hot spots” of infection through three interrelated mechanisms:

Environmental Phase: This component explicitly models the dynamics of infectious material in the soil, including decay rates and the role of earthworm burrowing in creating macropores that serve as conduits for accelerated pathogen movement.

Host–Vector Interaction: This component quantifies the rate at which host organisms — including livestock, poultry, and humans — encounter contaminated soil and earthworm castings. By concentrating PPNs within nutrient-rich castings (coprolites), earthworms increase the likelihood of contact between infective stages and susceptible host plant roots.

Infection Amplification: This component assesses how earthworm activity may enhance the basic reproduction number (R_0) of a pathogen by concentrating infectious material in localized “hot spots” or facilitating its spread to previously uninfested areas.

Collectively, these theoretical models treat the earthworm as a biogeochemical and physical agent that significantly reshapes the spatial and temporal dynamics of soil-borne pathogens, thereby modulating disease transmission risk beyond what would be expected of a traditional arthropod vector.

IV. RESULTS

Table 1. Distribution and Recovery of Plant-Parasitic Nematodes Across Soil Types and Moisture Levels

Soil Type	Moisture Content (%)	PPN Recovered (n)	Percentage (%)
Swampy	45	23	51.1
Semi-Dry	30	17	37.8
Dry	24	5	11.1

Source: Field Survey, 2025.

Figure 1. *Number of plant-parasitic nematodes recovered from Lumbricus terrestris (anecic) across three farmland types — swampy, semi-dry, and dry — in the Kolo Creek area.*

The recovery of PPNs from the gut contents of *L. terrestris* varied considerably across the three sampled

farmlands (Figure 1; Table 1). Earthworms collected from swampy farmland exhibited the highest PPN prevalence, accounting for 51% (n = 23) of the total recovery. Earthworms from semi-dry land yielded 37% (n = 17), while those from dry farmland recorded the lowest recovery at 11% (n = 5). A one-way ANOVA confirmed that moisture-related soil characteristics significantly influenced the vectorial capacity of *L. terrestris* ($P < 0.05$). Post-hoc Tukey’s HSD testing indicated that PPN counts in swampy environments were significantly higher than those in dry land, suggesting that high-moisture habitats enhance earthworm–nematode interaction and subsequent nematode ingestion rates.

Table 2. One-Way ANOVA Summary for PPN Recovery Across Soil Types

Source of Variation	SS	Df	MS	F-statistic	P-value
Between groups	544.0	2	272.0	11.41	0.009
Within groups	142.8	6	23.8	—	—
Total	686.8	8	—	—	—

Source: Field Survey, 2025.

The ANOVA yielded an F-statistic of 11.41 and a P-value of 0.009, which is below the standard significance threshold of $\alpha = 0.05$, confirming a statistically significant difference in PPN recovery rates across the three soil types (Table 2). Post-hoc pairwise comparisons using Tukey’s HSD test revealed the following:

Swampy vs. Dry: Significant difference ($P < 0.05$).
Swampy vs. Semi-Dry: No significant difference ($P > 0.05$).
Semi-Dry vs. Dry: Significant difference ($P < 0.05$).

V. DISCUSSION

The results confirm that *L. terrestris* functions as a mechanical vector for PPNs across all sampled soil types, with recovery rates strongly correlated with soil moisture. These findings are consistent with reports by Wilian et al. (2019), who noted that the effects of earthworms on soil nematode communities are highly variable, encompassing positive, negative, and neutral responses depending on edaphic conditions and earthworm density. The significant influence of soil type and moisture content observed here aligns with laboratory and field evidence (Zhu et al., 2024; Zheng et al., 2022) indicating that earthworms may either facilitate or suppress nematode populations depending on specific environmental parameters.

Notwithstanding the innate immune defenses described by Pulavarty et al. (2022) — including AMPs and coelomocyte-mediated responses — the present study found that these mechanisms appeared largely ineffective against PPNs. This resistance is likely attributable to the tough, chemically resistant outer cuticle of plant-parasitic nematodes, which may enable survival through the earthworm gut without significant degradation. This observation lends empirical support to the Immune Response Model presented in the theoretical framework.

Variation in PPN recovery across farmland types may be attributed to a range of interacting factors, including soil texture, moisture content, pH, climatic conditions, agricultural management practices, and the availability of host plant species. Research by Qian et al. (2024) on earthworm cultivation and associated bacterial communities further supports the conclusion that nematode loads associated with earthworms are contingent upon exposure levels, soil conditions, and broader ecological context.

The highest PPN recovery from swampy farmland (23 individuals; 51%) is consistent with findings by Niu et al. (2019), who demonstrated that anecic and epigeic earthworm species increased PPN densities in maize by approximately 27% relative to earthworm-free controls. High soil moisture in swampy environments likely promotes macropore formation during earthworm burrowing, enhancing soil conductivity for

both earthworm movement and nematode accessibility, as described in the Environmental Phase component of the Transmission Dynamics Model. Moreover, Gudeta et al. (2023) postulated that earthworm castings serve as vehicles for PPN dispersal, transforming nematodes that are naturally restricted to sub-millimeter movement into epidemiologically significant agents capable of long-distance dissemination.

Differences in PPN gut content among earthworm specimens may reflect variation in body size, feeding ecology, and burrowing depth. Li et al. (2024) reported that epigeic and anecic earthworms are capable of ingesting substantial quantities of PPNs, many of which survive gut passage unharmed and are subsequently deposited alive and active in castings at new locations. This represents a clear transport mechanism rather than a predatory or digestive relationship. Aira and Domínguez (2025) further confirmed that earthworms consume organic matter and plant root material containing PPN eggs and juvenile stages, which hatch upon deposition to infest new host plants. This vectorial role allows PPNs to disperse substantially beyond their natural range, contributing to the acceleration of infestation spread in cultivated fields. Taken together, these findings provide strong empirical support for both the Gut Environment Model and the Transmission Dynamics/Epidemiological Model, in which earthworms serve as critical agents of PPN mobility and spatial distribution.

5.1 Statistical Interpretation

The ANOVA results confirmed that soil moisture significantly influenced PPN vectorial capacity ($P < 0.05$, $F = 11.41$). Tukey’s HSD test demonstrated that PPN recovery in high-moisture swampy environments (45% moisture content) was significantly greater than in dry land (24% moisture), while recovery in semi-dry land was not significantly different from that in swampy land. These outcomes suggest a threshold moisture effect, whereby high moisture substantially enhances earthworm–nematode interaction rates. From a mechanistic perspective, elevated soil moisture facilitates enhanced macropore (conduit) formation through earthworm burrowing, increasing the accessibility of PPNs to earthworms and their subsequent deposition via castings. Furthermore, the concentration of PPNs within nutrient-rich coprolites deposited in high-moisture “hot spots” amplifies the local infective pressure on host plant roots, consistent with the Infection Amplification component of the epidemiological framework.

VI. CONCLUSION AND RECOMMENDATIONS

This study confirms that *Lumbricus terrestris* serves as a significant mechanical vector for PPNs in the agricultural soils of the Kolo Creek area, Nigeria. Despite the severely limited independent motility of PPNs — typically less than one millimeter over their lifespan — earthworms facilitate their active dispersal by ingesting viable nematodes and depositing them, alive and infective, in castings (coprolites) at new locations. Soil moisture emerged as a critical determinant of earthworm vectorial capacity, with significantly higher PPN recovery rates observed in high-moisture swampy environments compared to dry farmland.

These findings carry important implications for the sustainable management of nematode infestations in tropical agroecosystems. The following evidence-based recommendations are proposed:

Drainage Improvement: Improving drainage infrastructure in swampy farmlands can reduce soil moisture to levels less conducive to earthworm–nematode interaction, thereby limiting the rapid spread of PPN infestations.

Integrated Pest Management (IPM): Farmers should monitor earthworm casting “hot spots” — areas of elevated cast density in high-moisture zones — as primary sites for early nematode outbreak detection and intervention.

Targeted Biocontrol: Future research should investigate biological control agents capable of suppressing PPNs in earthworm gut environments or in castings, without compromising earthworm populations or their broader ecosystem services.

Expanded Field Studies: Longitudinal, multi-site investigations incorporating a wider range of soil types, earthworm species, and host crops are needed to generalize these findings and refine epidemiological models of PPN dispersal in tropical agroecosystems.

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