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Effects of Earthworms on Microbial Communities and Their Castings as Soil Amendments: A Review

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Abstract

Earthworms play a crucial role in ecosystem functions and services, particularly in shaping soil structure and promoting water infiltration, litter decomposition, and nitrogen mineralization. Their activities modify physical and chemical soil properties, which in turn affect microbial community composition and activity. Several analyses revealed that earthworm casts serve as organic soil amendments that positively impact soil physical, chemical, and biological properties. Earthworms influence microbial communities by selectively digesting microorganisms and promoting the growth of beneficial bacteria. These findings demonstrate the importance of earthworms as ecological mediators that can enhance soil functions and promote sustainable agricultural practices. This review paper has summarized earthworm casting as a soil amendment and its effects on microbial communities by reviewing relevant related works. To achieve this goal, the Google Scholar, Frontier in Microbiology, PubMed, Scopus, Web of Science, Science Direct and Directory of Open Access Journals (DOAJ) databases were explored to identify studies on earthworm casting as a soil amendment in relation to microbial communities.

Keywords: Earthworm, Casting, Microbial Communities, Soil Properties, Amendments.

1. Introduction

Among the soil fauna, earthworms are acknowledged for their role in ecosystem functions and services, as they shape the soil structure; protect organic material against mineralization, as they are mixed with soil particles; promote water infiltration, litter decomposition and nitrogen mineralization; and dominate the biomass of soil fauna in most biomes [1, 2]. Earthworms modify physical and chemical soil properties by burrowing, casting and mixing litter and soil, thus altering habitat structure and nutrient availability. By influencing microhabitats, earthworms may change microbial community composition, biomass and activity and thus indirectly affect nitrogen cycling. In the presence of earthworms, microbial communities switch to smaller but more active communities, and nitrogen-related microbial enzyme activity increases [3, 4].

Earthworm castings are also known as vermicasts and serve as organic soil amendments that greatly impact the physical, chemical, and biological properties of soil, transforming it into a living, fertile medium [5]. Cast production has been reported to be influenced by increasing soil pH and Ca levels, soil moisture, temperature, and food supply; shading and litterfall; land use patterns; and vegetation and environmental conditions [6-11]. This review paper summarizes the effects of earthworms on microbial communities and explores their use as soil amendments. This paper review collected relevant articles from various databases, focusing on the effects of earthworms on soil microbial communities and the use of earthworm casting as a soil amendment.

2. Methodology

A literature review was carried out to identify the relevant articles published. Google Scholar, Frontier in Microbiology, PubMed, Scopus, Web of Science, Science Direct and Directory of Open Access Journals (DOAJ) databases were searched to identify studies on the effects of earthworms on soil microbial communities and their casting as soil amendments using the following keywords in English: ‘earthworm casting as soil amendments’, ‘effect of earthworm on soil microbial communities’, and ‘effect of soil earthworm on soil properties’. A total of 300 articles were identified in the initial review, but 50 articles were selected to be good matches for the review study based on the objective of the study, geographical location and specific areas of interest.

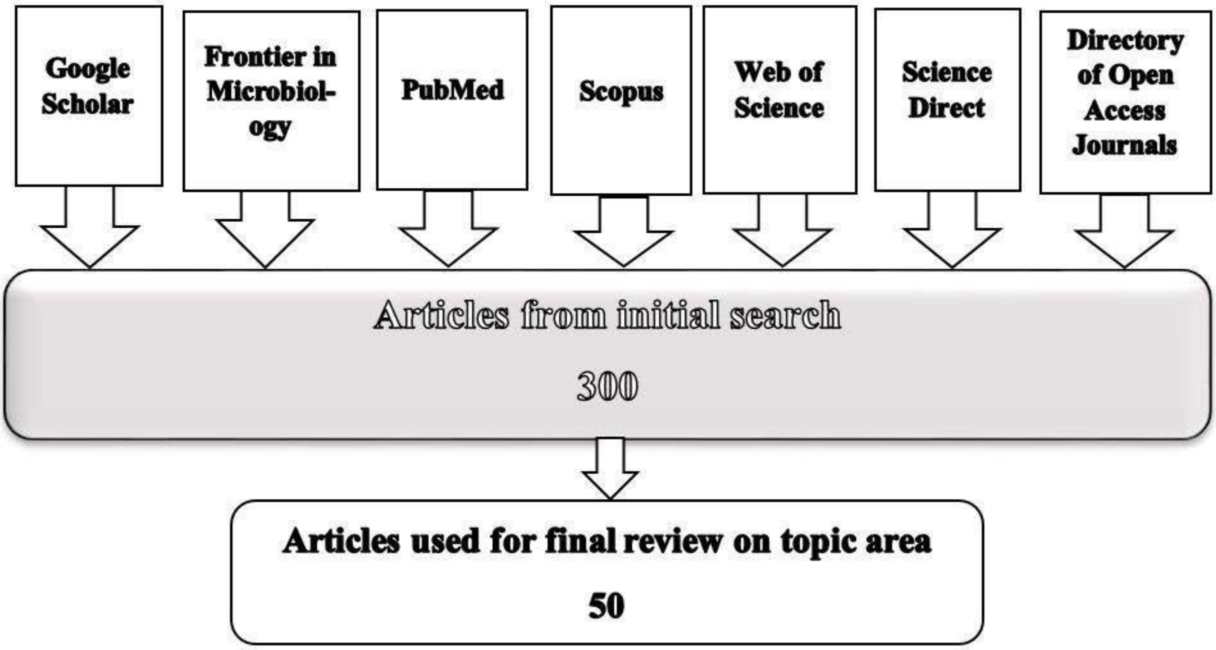

Figure 1: Flow Chart Showing the Methodology used to Review the Literature.

3. Discussion

3.1. Earthworm in Soil

Earthworms are found worldwide, except in snowy and very hot regions, because earthworms are very temperature sensitive; however, they have diverse habitats where nutrient-rich organic matter is easily available, such as gardens and paddy fields, and places rich in moisture contents of nearly 55 to 60% [12]. Earthworms are considered ecosystem engineers that play an important role in shaping soil structure and cycling nutrients [2]. Earthworms promote litter decomposition, nitrogen (N) mineralization and water infiltration as a result of their feeding and burrowing habits and therefore strongly affect soil properties [13, 14]. They also play a crucial role in the provision of soil ecosystem services.

The soil volume is directly influenced by earthworms, known as the drilosphere, which is an important functional region of the soil that is made up of the earthworm community and the structures it creates, namely, middens, burrows, tunnels, and casts. Earthworms are thus builders of habitats for other organisms, which establish them as physical or allogenic engineers [5, 15]. In addition, these building activities constitute an input of organic matter to the soil and a pathway for the stabilization of soil organic carbon through the formation of organomineral aggregates [16]. This enrichment in organic matter mainly results from earthworm food choices and from earthworm digestion and the excretion of intestinal or cutaneous mucus, which can be used as a cementing or energy source [17, 18].

In addition to shaping the soil structure, earthworms also have an important impact on soil organic matter dynamics and microorganisms in the gut, casts and drilosphere and are also identified as biochemical or autogenic ecosystem engineers [5, 19]. Earthworms are considered key ecological mediators that can affect soil functions and microbial activities by producing energy-rich mucus that activates microorganisms through a priming effect and signaling molecules that have hormone-like effects and influence plant gene expression [5, 20]. They have a direct and important effect on the soil microbiota through their nutritional status. This effect may depend on their food preference, selection, food ingestion rate, digestion and assimilation, as mentioned by Curry & Schmidt [18]. Earthworms can digest microorganisms, thereby decreasing microbial biomass, especially that of fungi [20, 21]. They may also select or stimulate soil microbes that help them digest soil organic matter since the earthworm gut often lacks sufficient enzymes to do so [23, 24].

This process may enrich the soil for certain bacterial taxa, for example, bacteria able to decompose the organic matter that earthworms feed on or denitrifying bacteria able to survive in the reduced oxygen conditions of the earthworm gut [25]. Understanding the physiology, morphology and behavior of earthworms is essential for understanding their effects on soil functions. However, there is increasing evidence that the effect of earthworms on soil functions may be mediated through soil microbial communities. It is yet unclear how different ecological groups may promote or select soil microorganisms, and there are many contradictory results concerning the effect of earthworms on soil microbial communities [26]. However, the drilosphere is generally acknowledged as a soil hotspot with a positive effect on ecosystem functions such as nutrient cycling and plant growth [27, 28].

3.2. Classification of Earthworms Based on Their Ecological Adaptations

Based on their ecological adaptations, they are divided into two categories: microdrilli and megadrilli. Of the 3627 earthworm species, 280 were microdrilli; these are aquatic species, and the rest were megadrilli species. Furthermore,

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megadrilli can be classified into three subgroups depending on the inhabiting layer of the soil [29].

Epigeic Earthworms (e.g., Eisenia fetida, Eudrilus eugeniae, and Perionyx excavatus): Epigeic earthworms are surface feeder detritivorous worms that feed on surface debris; decay organic wastes such as crop residues; decay organic wastes; leaf litter; plant roots; and animal dung and convert them into vermicast. Due to their short lifespan, the fecundity rate of these plants is high, and epigeic earthworms reproduce in diverse habitats and harsh environments [30]. *E. fetida* is the most suitable species for vermiculture worldwide. Epigeic earthworms are small in size; they are 1 to 18 cm in length [31]. Yakushev et al. reported an increase in microbial biomass of 2.7 times in the casts of *E. fetida* and reported that microbial growth over a period of 9 h was 124 times greater in vermicomposts than in composts [32]. With a mixture of pig manure and soil, the microbial biomass was 1.3 times greater in the presence of earthworms [33]. Toyota and Kimura reported that bacterial biomass, evaluated by counting colony forming units (CFU), increased from 3.2 × 104 CFU g^{-1} in composted farmyard manure to 1.3 × 107 CFU g^{-1} in vermicompost with *E. fetida* [34]. Although other studies have shown that epigeic earthworms do not have any impact on microbial abundance in the soil, this effect seems to be dependent upon the kind of feedstock assessed. On leaf compost from alder, willow and birch plants with a C/N = 19.2, the presence of *E. fetida/E. andrei* induced a great increase in the number of microorganisms, whereas vermicompost made from cattle manure (C/N = 15.4) did not significantly differ from its respective control compost without earthworms (C/N = 16.5) [32].

The Endogeics Species (e.g., Allolobophora chlorotica, Apporectodea icterica, Murchieona muldali, Octolasion cyaneum and Octolasion lacteum): Endogeic species of earthworms are soil-inhabiting organisms that are not surface dwellers but live beneath the topsoil. The body size of the endogeic species ranges from 2.5 to 30 cm in length. Endogeic species build horizontal burrows in the soil [35]. Endogeic species are the native species of Australian continents and are commonly found in New Zealand [36]. The feeding material of this species is soil, which contains less organic matter than surface layer feeding material. The soil texture is mainly altered by these species because endogeic earthworms feed more soil and less organic matter. These earthworms are not suitable for vermicomposting but are good for improving soil structure. The fecundity rate was lower than that of epigeia. The life span of these earthworms is relatively longer than that of epigeic earthworms [36].

Anecics (e.g., Aporrectodea longa, Aporrectodea nocturna, Lumbricus friendi and Lumbricus terrestris): Anecic earthworms live in the deeper part of the soil in vertical burrows. The plants lived in the soil at a depth of 3 meters. Anecic earthworms make vertical burrows approximately 2 cm in diameter. These species are the longest species category because anecic earthworms are approximately 3 cm to 20 cm long. Anecic earthworms help mix organic nutrients in the soil and enhance the soil texture (paedogenesis). Anecic earthworms come out from their burrows at night and move to the soil surface, where they eat decaying organic matter with some part of the soil. This species of earthworm is not suitable for vermiculture because of the low decomposition efficacy of organic matter; additionally, compared with epigeic and endogeic earthworms, which have a low fecundity but also anecic earthworms, which have a longer life span [37]. Sheehan et al. observed a differential impact of the anecic worms *Lumbricus friendi* and *Aporrectodea longa* on microbial biomass depending on the soil horizon under study [38]. In a microcosm experiment using soil and litter from lime (*Tilia cordia*), compared with the surrounding soil, the anecic L. terrestris induced more microbial biomass in soil retrieved from its burrow walls [39].

3.3. Effect of Earthworm and its Cast on Soil Microbial Diversity

Numerous studies have investigated the impact of earthworm casts on soil microbial diversity. For instance, Zheng et al. observed a significant increase in bacterial and fungal diversity in soils amended with earthworm casts compared to control soils [40]. The presence of diverse microbial communities in amended soils contributes to improved nutrient availability and cycling. Edwards and Bohlen reported that earthworm cast application increased microbial biomass and diversity in agricultural soils, while Dominguez et al. reported significant changes in the bacterial and fungal community structures after earthworm cast application in forest soils [41, 42]. In a study by Kumar et al., soils treated with earthworm casts exhibited higher microbial biomass carbon and nitrogen levels than did untreated soils [43].

This increase in microbial biomass signifies the potential of earthworm casts to improve soil health. Moreover, Chaoui et al. revealed alterations in the relative abundances of specific microbial phyla and genera in earthworm cast-amended soils [44]. These shifts may have implications for soil functionality and nutrient dynamics. According to Edwards and Bohlen, enzymes such as cellulases, amylases, and proteases present in earthworm casts play vital roles in substrate decomposition and nutrient release, stimulating microbial activity and diversity [45]. The introduction of earthworms as amendments can also positively influence plant–microbe interactions. Research by Hodson et al. demonstrated that earthworm cast application led to the proliferation of beneficial mycorrhizal fungi, which, in turn, enhanced nutrient uptake and plant growth [46].

Table 1: Effects of Earthworms on Soil Microbes

Authors & Year	Experimental Type/ Location	Effects on Soil Microbes/ Areas	Earthworm Species
Darby et al. [72]	Northern hardwood forest soils	Decreased microbial biomass	Invasive worms
Eisenhauer et al. [74]	Grassland	Earthworm species influence soil microbial community	Aporrectodea caliginosa, Lumbricus terrestris
Griffiths et al. [75]	Arable & grassland ecosystems	Earthworm effects on soil bacteria, fungi, and protozoa	Lumbricus terrestris, Aporrectodea caliginosa, Aporrectodea longa
Drigo et al. [73]	Agricultural fields	Influence of earthworms on microbial functional diversity	Aporrectodea caliginosa, Lumbricus terrestris
Goncharov et al. [77]	Boreal forest, Russia	Effects on microbial communities in boreal soil	Aporrectodea caliginosa
Source: Author's compilation			

3.4. Earthworm Cast as a Soil Amendment

Earthworm casts are the byproduct of the biodegradation of soil organic matter by earthworms. Earthworms can produce up to 5–10 times their own weight in casts in one day [47]. Castings have been shown to absorb water faster than soil and hold more water than equivalent amounts of soil, thereby increasing moisture absorption and moisture availability to plants. Furthermore, castings are known to absorb moisture from the air and hold it for plant use. Casting also holds nutrients for plant use as a nonpollutant natural fertilizer. An important component of casting materials is humic acid, which provides binding sites for plant nutrients such as calcium, iron, potassium, sulfur and phosphorus and releases them upon demand [48]. Casts have been shown to have enhanced microbial and enzyme activities and micro- and macronutrients when added to soil as amendments [49].

The quantity of earthworm casts in temperate soils ranges from 75–250 t ha-1 yr-1, and this value is even greater in tropical grasslands. The beneficial effects of earthworm cast utilization have been proven in agriculture and horticulture [50]. In recent years, earthworm casts have been widely used in agricultural production due to their advantageous physical and chemical properties. As earthworm casts are rich in humus and nutrients, they have a high capacity for adsorbing and releasing fertilizers. Various studies have shown that earthworm casting can significantly increase soil structural stability [51-53]. Lim et al. noted that earthworm casts are apparently uniform and porous in structure, with a large surface area and deep, dark color [54]. When an earthworm is applied to the soil, the color of the soil becomes darker, and the soil temperature increases as a result of increased absorption of light energy from sunlight [55]. Furthermore, earthworm casts usually have a lower bulk density than surrounding soils. As a result of earthworm cast application, the abundance and activity of microorganisms in the soil are considerably enhanced, and soil aggregates form easily, thereby increasing the total porosity and decreasing the bulk density of the soil [56, 57].

3.5. The Impact of Earthworms and their Casts on Nutrient Cycling

In a study, Braga et al. showed that the introduction of the endogeic *P. corethrurus* into the soil significantly changed approximately 70 microbial functions in the bulk soil and in the rhizosphere, which were mainly related to biosynthesis and plant–microbe symbiosis [57]. The presence of earthworms also modified the ecological interactions among microbial functions. As shown in the previous section, earthworms stimulate certain microbial taxa and, by doing so, increase the importance of keystone functions [57]. Earthworms, in particular, endogeic geophagous earthworms, are known to promote C and N mineralization in the soil, most likely through a priming effect affecting decomposition rates of the soil organic matter (SOM) [58-60]. This positive priming effect is expected to promote the recycling of nutrients, especially organic N and P, in the SOM [61]. This phenomenon has been shown for *P. corethrurus* in several studies, as summarized in a review by Taheri et al. [62]. Two- to threefold increases in mineralized C have also been observed in casts of the endogeic *A. caliginosa* compared with the surrounding soil, which is attributed to the priming effect caused by earthworm ingestion and digestion. Epigeic earthworms such as *E. fetida* and *P. excavatus* have also been reported to enhance the decomposition rates of organic matter [63]. The increase in SOM mineralization in earthworm casts, compared with that in the surrounding soil, is associated with an enrichment in labile compounds and with a subsequent increase in microbial activity, which could be attributed to earthworm digestion itself and to the influence of the gut microbiome [59, 65].

3.6. Earthworms as Bioindicators of Soil Fertility and Health

Earthworms are biological indicators of the soil ecosystem because they indicate the health and fertility of the soil for proper cropping [64]. The number of earthworms in the soil determines the health of the soil and indicates the presence of microorganisms such as bacteria, fungi, viruses and other organisms in the soil; a high number of earthworms indicates high biodiversity of the microorganisms in the soil [65].

Table 2: Effects of Earthworms on Soil Properties

Authors and Year	Effects on Soil Properties/Areas	Experimental Type/Locations	Earthworm Species
Dominguez et al. [78]	Enhanced nutrient content & microbial activity	Organic amended soils	Eisenia fetida
Das et al. [76]	Increased nutrient availability and microbial biomass	Tropical soils	Eudrilus eugeniae
Arancon et al. [70]	Enhanced nutrient content and microbial activity	Tropical soils	Eudrilus eugeniae
Bohlen et al. [71]	Impacts on soil carbon dynamics and microbial activity	Boreal forest, Sweden	Lumbricus terrestris
Source: Author’s compilation			

A prominent microbial community is present in a rich organic matter area, as are many organisms, such as bacteria; fungi are present there because the decomposition of organic nutrients by vermicompost is high [66]. The bacterial community and fungal hyphae associated with plants enhance soil productivity [67, 68]. A high microbial population of bacteria, fungi, and actinomycetes and greater enzymatic activity have been detected in soils where the earthworm population is high and where greater earthworm diversity is also associated with greater microbial diversity, which helps in crop yield production without the use of chemical fertilizers [69-78].

4. Conclusion

Earthworms are ecologically important soil organisms that significantly influence soil properties and microbial communities. The burrowing, casting, and feeding activities of these plants alter the soil habitat, promoting water infiltration and nutrient cycling. Earthworm casts serve as valuable organic soil amendments, enhancing soil fertility and microbial activity. The influence of earthworms on soil functions is mediated through the alteration of microbial communities, leading to improved nutrient availability and cycling. This review emphasizes the need to consider earthworms as key indicators of soil fertility and health. The presence and abundance of earthworms can serve as indicators of microbial diversity, providing valuable insights into soil ecosystem health. Sustainable agricultural practices can benefit from incorporating earthworms and their castings as a natural means of enhancing soil quality and fertility. Overall, this review highlights the importance of understanding the interactions between earthworms and microbial communities and soil functions. Further research is necessary to elucidate the specific mechanisms underlying earthworm-microbe interactions and their implications for sustainable land management practices. By recognizing the essential role of earthworms in soil health, we can develop strategies that harness their ecological functions to improve agricultural productivity while preserving ecosystem integrity.

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