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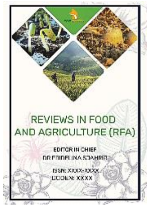
Reviews In Food And Agriculture (RFNA)

DOI: http://doi.org/10.26480/rfna.01.2024.06.12

ISSN: 2735-0312 (Online)
CODEN: RFAEAW



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RESEARCH ARTICLE

BENEATH THE SURFACE: EARTHWORMS AND THEIR BENEFICIAL IMPACTS ON FARMING COMMUNITIES

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ARTICLE DETAILS

Article History:

Received 20 February 2024
Revised 04 March 2024
Accepted 22 April 2024
Available online 29 April 2024

ABSTRACT

The oligochaete annelid family of earthworms plays a crucial role in soil ecological groupings since they facilitate decomposition and the nutrient cycling of ecosystems. In most terrestrial habitats, earthworms are the dominant members of the soil macrofauna (> 4mm) groups. They are among the most important coprophages and detritivores in the natural world, and they feed a lot of ecosystems' lower-level consumers. This study was carried out to comprehend the many kinds of earthworms and their taxonomy through in-depth reviews. The interaction between earthworms and soil fertility—including aggregate formation, soil aeration, nutrient management, and other factors—is another area of interest for this study. The negative impact of intensive farming on the environment and public health is often criticized. A better understanding of the creatures living in crop fields could be the solution to this issue. The ability of earthworms to extract energy, nutrients, water, and climate buffering from soil is one of their primary advantages. Earthworms play a major role in the biological processes of nutrient cycling in soils, and the makeup of their populations gives insight into the type of soil system in which they reside. By transforming organic waste and biodegradable materials into nutrient-rich products that emerge from their tunnels to deposit fecal matter on the soil's surface, earthworms preserve the physiochemical qualities of the soil. In addition to mixing and agglomerating the soil, they also increase microbiological activity and soil water content and capacity. Given that farming can involve a variety of soil-disturbing activities, an understanding of the biology and ecology of earthworms may help in the development of management approaches that may alter soil biota and crop performance. Lastly, we discuss how to combine management strategies, including vaccination, to improve earthworm services. We draw the conclusion that using earthworm services in soil systems may be able to improve agricultural sustainability.

KEYWORDS

Earthworm, Soil aeration, Soil fertility, Sustainability, Vermicompost

1. INTRODUCTION

When it comes to the creation of soil and the preservation of soil fertility and structure, earthworms are perhaps the most significant members of the soil biota (Akhila and Entoori, 2022). One of the earliest people to identify the role earthworms play in changing soil was Aristotle, who called them "The Intestines of the Earth". But it wasn't until the late 1800s that Charles Darwin stressed the vital role that earthworms play in the continuous turnover and maintenance of soil structure, aeration, drainage, and fertility. This was done in his seminal work The Formation of Vegetable Mould through the Action of a study which detailed the breakdown of dead plant and animal matter that reaches soils (Worms, 1881).

Terrestrial oligochaetes that live on soil are called earthworms (Crassiclitellata). According to a study, earthworms vary in size from a few millimeters to up to two meters in length, from 10 milligrams to almost a kilogram, and from 40 mm in diameter (Kiyasudeen et al., 2016). In most temperate settings, these invertebrates make up the bulk of the animal biomass and have a large effect on the biological, chemical, and physical properties of the soil (Curry, 2004). They can be found in agroecosystems, natural forests, and grasslands all throughout the world. Numerous factors, such as soil type, pH, soil moisture-holding capacity, rainfall, and ambient temperatures, affect population size; nevertheless, the most important factor is the availability of organic matter (Dekemati et al., 2019). This is because earthworms get their sustenance from the interactions between organic debris and bacteria. They have a significant impact on the structure and composition of the aboveground plant community by altering the soil's structure, accelerating the breakdown of organic matter, and promoting nutrient cycling (Filser et al., 2016).

The activity of earthworms varies greatly throughout the year in temperate regions, where they are mostly active in the spring and fall. They dig farther into the earth during the winter, where they are better protected from the bitter cold (Nuutinen and Butt, 2009). During dry summers, they also burrow deeper into the ground, often creating mucus-lined chambers where they estivate in a coil shape until the weather improves (Holmstrup and Zachariassen, 1996). Most earthworm species cannot survive beyond 30 to 35°C, and many species cannot survive below 0°C (Edwards, 1983).

Quick Response Code	Access this article online	
	Website: www.rfna.com.my	**DOI:** 10.26480/rfna.01.2024.06.12

Cite The Article: Saurav Marahatta, Jay Chaurasia, Vivek Ghimirey, Suresh Raj Dahal (2024). Beneath the Surface: Earthworms and their Beneficial Impacts on Farming Communities. *Reviews In Food And Agriculture, 4(1): 06-12.*

Earthworms have a simple body structure and a digging habit. On the other side, there are about 6000 species of earthworms, a diverse group of annelids that burrow (Dominguez, 2018). For the great majority of species, just their name and morphology are known; their biology and ecology remain unknown. This document highlights the different species of earthworms and their classification. Another area of interest for this study is the relationship between earthworms and soil fertility, including aggregate formation, soil aeration, nutrient management, and other aspects. Due to the country's growing population, per capita income, urbanization, nutrient awareness, and tourism industry, fruit and vegetables are in high demand (Ghimirey et al., 2023). One of the most viable solutions to this problem is the use of earthworms in agriculture.

2. Methodology

The article was created by using secondary data and information from government publications, academic research papers, reports from different organizations, and pertinent websites. A systematic research methodology was adopted. Using electronic resources including Google Scholar, PubMed, Scopus (Elsevier), Web of Science, Semantic Scholar, Academia, and other relevant websites, a thorough search of the corpus of literature was conducted. After closely examining these sources, the findings were summarized.

3. Results and Discussion

3.1 Types of Earthworms

Different kinds of earthworms inhabit different ecological niches and have unique life methods. Thus, earthworms can be divided into three broad ecological groups according to the areas of the soil profile they live in and the kinds of food they ingest. Certain species cannot be reliably placed into any of these classifications, and others can be challenging to define. Compared to soils in grasslands and forests, earthworms burrow farther in agricultural soils.

3.1.1 Epigeic Earthworms

According to some researchers epigeic earthworms are found in the organic horizon, which is the area on or near the soil's surface (Kiyasudeen et al., 2016). They mostly consume decomposing organic debris, such as vegetable and animal waste. They can adapt to the shifting environmental conditions of the soil surface since they are usually small, pigmented, and have fast metabolic and reproductive rates (Edwards and Arancon, 2022). Additionally, they rapidly take in, process, and absorb organic waste. They also modify the litter by producing hologanic castings, which is an important function they do. The following species are epigeic lumbricids: *Dendrodrilus rubidus, Eiseniella tetraedra, Allolobophoridella eiseni, Eisenia fetida, Eisenia Andrei*, and *Dendrobaena veneta, hortensis*, and *octaedra*.

3.1.2 Endogeic Earthworms

Deeper in the soil profile, endogeic earthworms mostly consume organic waste and dirt. As they go through the soil's organic-mineral horizon, these worms—which have no pigmentation—create extremely branched horizontal tunnels that eventually fill with waste (Zanella et al., 2018). In comparison to epigeic earthworms, endogeic earthworms reproduce more slowly, have longer life cycles, and are more resilient to unfavorable conditions like starvation and drought (Le Bayon et al., 2021). This group includes the majority of earthworms, such as *Aporrectodea caliginosa*, *Aporrectodea rosea*, and *Octolasion lacteum*.

3.1.3 Anecic Earthworms

The whole life of an angecic earthworm is spent in vertical tunnels that extend several meters into the soil profile. These animals emerge at night to feed on organic waste that has decomposed and litter, which they then carry back to their galleries. At the entrances to their galleries, they deposit their excrement on the surface in the form of discernible earthworm casts (Lavelle et al., 2007). These dark brown earthworms are frequently enormous. Their life periods are relatively long, and their reproduction rates are moderate. Anecic earthworms, such as *Lumbricus terrestris*, are known as night crawlers (Domínguez, 2018).

3.2 Taxonomic details of earthworm for vermicomposting

The majority of scientists understand the significance of taxonomy, and most ecological research are pointless without sound taxonomy (Domínguez et al., 2005). Due to the structural simplicity of the earthworm body plan—which lacks highly specialized copulatory appendages or anatomically complex structures—taxonomic identification based on physical features is challenging in many earthworm species (POP et al., 2003). While there are many earthworm species with potential for vermicomposting around the world, including *Eisenia foetida, Dendrodrilus rubidus, Lumbricus rubellus, Drawida nepalensis, Eudrilus eugeniae, Perionyx excavatus*, and *Polypheretima elongata*, most vermiculture operations in Southeast Asia use *Eisenia foetida* and *Eisenia andrei* because these species are epigeic and exhibit traits like high rates of processing organic wastes, high reproductive rates, and tolerance to a wide range of environmental factors (Dominguez, 2004).

These closely related earthworm species, *Eisenia fetida* and *Eisenia andrei*, are widely used in ecotoxicological, physiological, and genetic studies, as well as in vermicomposting systems for recycling organic waste (see Figure 1). These species are widely used because they are easy to handle, have short life cycles, high rates of reproduction, can withstand changes in humidity and temperature, and are widely distributed (Domínguez, 2004). Kingdom, Phylum, Class, Order, Family, Genus, and Species are the seven classifications used in biological taxonomy (Clairenstein, 2022).

Kingdom: Animalia

Phylum: Annelida

Class: Oligochaeta

Order: Haplotaxida

Family: Lumbricidae

Genus: *Eisenia*

Species: *E.andrei, E. fetida*

Figure 1: *Eisenia andrei* (top panel) and *Eisenia fetida* (bottom panel)

The colloquial names "striped worm" and "tiger worm" originate from *Eisenia fetida*, the striped morph, where the area between the segments is either yellow or light yellow in color or lacks pigmentation. In contrast, the common red worm, *E. andrei*, has a uniform red color. With the exception of variations in pigmentation, the species are comparable physically and have similar biological characteristics, including life cycles and the ability for reproduction. However, *E. andrei* grows and produces cocoons at slightly higher rates than *E. fetida* (Elvira et al., 1996).

3.3 Earthworms and soil fertility

Through eating, burrowing, and casting, earthworms alter the biological, chemical, and physical characteristics of soil organic matter (Brown and Double, 2004). Earthworm activity improves the physical properties of organic matter, such as aggregation, stability, and porosity. The chemical characteristics of soil that earthworms process include the dynamics of organic matter in terms of quality and quantity, nutrient cycling, chemical forms of nutrients in soil, and their availability to plants. Earthworms have an impact on species composition, diversity, biomass, microbial and invertebrate activity, and abundance (Lavelle et al., 1998). A variety of organic compounds and polysaccharides, such as cellulose, sugars, chitin, lignin, starch, and polylactic acids, can be broken down by the potentially active microbial population found in the gut and cast of earthworms (Huang et al., 2023).

3.3.1 Soil Formation Differentiation

Earthworms are essential to the creation of soil because they break down organic matter, mix it with soil mineral particles in close proximity, and use this process to create aggregates that withstand water. When earthworms consume, their microbial activity increases, hastening the humic components of organic matter's breakdown and stability (Wolters, 2000). All earthworm species contribute in different ways to the comminution and mixing of soil's organic and inorganic components, as well as to the reduction of the size of both organic and mineral particles (Scullion and Malik, 2000). Species may leave their excrement as casts on the soil's surface or within their burrows. As the various mineral particles move through the stomach of the earthworm, they closely mix with the organic matter to produce aggregates that improve the soil's ability to drain and hold onto moisture (Guhra et al., 2022). These aggregates enhance many of the beneficial qualities of the soil and are often very water resistant. Many ideas have been put out to explain how earthworms create aggregates, such as the creation of polysaccharide molecules, plant remnants, gums, or calcium humate (Hafez et al., 2020).

3.3.2 Turnover of the soil

The swallowing of soil, the partial breakdown of organic materials, the intimate mixing of different fractions, and the ejection of this material as surface or subsurface casts are the earthworm activities that have the most effects on soil structure. Burrowing through the earth brings subsoil to the surface. Earthworms carry large amounts of soil up to the surface from deeper strata (Johnson et al., 2005). According to a study, the volumes moved in this way range from 2 to 250 tons per hectare year, which is comparable to yearly raising a layer of soil between 1 mm and 5 cm thick to the surface and creating a layer free of stones on the soil surface (Laird et al., 1981). In temperate locations, the top 15 cm of soil can be completely turned over every 10 to 20 years (Eggleton et al., 2009). Conversely, there has been a significant increase in turnover observed in tropical agroecosystems.

3.3.3 Soil aeration and drainage

For the purpose of preserving soil aeration, drainage, and porosity, both permanent burrows and cracks are crucial. According to a study, earthworm burrows can raise the soil-air volume from 8% to 30% of the overall soil volume (Shipitalo et al., 2004). There have been instances of water penetrating two to ten times faster when earthworms are present due to the burrows' increased infiltration rate (Kemper et al., 2011). By creating channels that let air into the soil's deeper layers, earthworm activity helps aerate the soil and lessens the likelihood of anaerobic layers forming.

3.3.4 Nutrient Availability

When earthworms eat, the C:N ratio in organic matter decreases and most of the nitrogen is converted to ammonium or nitrate form (Bohlen et al., 2004). Potassium and phosphorus, the remaining nutrients, are likewise converted into a form that is utilised by plants.

3.3.5 Aggregates Formation

Mineral granules bound together so they can resist compaction, wetting, and erosion while staying loose in both wet and dry soil are known as aggregates. Most experts agree that earthworm casts have a higher concentration of water-stable aggregates than the surrounding soil. According to a study, the application of humic acids made from vermicompost causes a notable accumulation of N, P, K, Ca, and Mg in the root and shoot system, which is connected to plant nutrient uptake (Maji et al., 2017).

3.3.6 Organic matter breakdown and incorporation into soil

While all earthworm species participate in the decomposition of organic matter obtained from plants, the processes by which they accomplish this and incorporate it into the soil are significantly different. They are capable of three different kind of behavior, each associated with a certain group of animals. According to a study, several species are confined to the plant-litter layer on the soil's surface, decomposing organic debris, or wood, and they hardly ever go deeper than a few millimeters into the soil (Brown et al., 2004). These organisms' main job seems to be breaking down organic molecules into little bits so that microbial activity can occur.

Other species live mostly below the soil's surface, do not dig permanent burrows, and consume both organic and inorganic materials—that is, unless the weather is exceptionally dry or frigid. These species produce discrete or random casts that are organically enriched soil components that are then deposited on the soil's surface (Hoeffner et al., 2018).

The actual soil-dwelling species are the last group; they have permanent, deep burrows. According to other study, these species consume a lot of inorganic matter in addition to predominantly organic matter, which they mix together in the soil profile (Munnoli et al., 2010). In one way or another, all species eat organic waste, and they are essential to the last stages of decomposition, where they humify into complex, amorphous colloids that contain phenolic chemicals. They probably do this by encouraging microbial activity.

In many ecosystems, earthworms are without a doubt the most significant creatures involved in the decomposition of plant organic matter. Populations of earthworms usually increase in response to the presence of organic matter.

3.3.7 Indicator of soil health

The capacity of a soil to support biological production, environmental integrity, and the health of plants, animals, and people is known as soil quality. Since earthworms are simple to collect and identify, soil ecologists and the majority of farmers concur that earthworms are among the best indicators of soil quality available (Rombke et al., 2005).

3.4 Effects of earthworm on crop yields

Since earthworms are now recognized to improve soil quality, numerous studies have attempted to demonstrate how these benefits translate into higher agricultural yields. The beneficial effects of earthworms on plant growth may be explained by the high quantities of macro- and micronutrients that are present in their secretions and vermicasts.

- Suthar found that adding 0.5 g (live weight) of earthworms to every kg of soil in a pot experiment increased dry matter yields by about 25% (Suthar, 2012). He attributed these increases to improvements in the physical condition of soils, such as less evaporation from worm-infested pots because the soil surface was covered by casts. While pea yields decreased, the dry matter yield of spring wheat planted in the soil, yields of four folded grass, and yields of ten folded clover increased when large numbers of earthworms were added to the soil (Boguzas et al., 2022).
- On the other hand, live worms added to garden soil have been shown by Kahsnitz to enhance yields by 70% for peas and oats (Kahsnitz, 1962).
- Van Rhee created a well-known illustration of how earthworms affect the development of apple tree roots. He saw a 40% increase in root density and a 70% improvement in aggregate stability. The average yield improved by 5% as a result of these changes.
- Earthworms are said to generate chemicals that aid in plant growth (Atiyeh et al., 2002).

3.5 Earthworm as biocontrol agents

There are several potential pathways for how earthworm activity suppresses disease, including effects on soil microbial populations, enzymatic activity, the production of antifungal compounds, soil physicochemical properties, and systemic resistance in plants (Datta et al., 2016). Earthworms use a variety of strategies to directly and indirectly modify the population of soil microbes, including comminution, burrowing and casting, grazing, and dispersal (Lemtiri et al., 2014). Increased microbial activity, which is frequently observed in vermicompost, leads to increased competition for components of root exudates between the fungal pathogen and microorganisms that inhabit compost (Mehta et al., 2012). By consuming certain fungal species, influencing the germination of ingested spores after they leave the earthworm, modifying fungal successional patterns, spreading particular fungus, modifying substrate quality, and lowering the inoculum potential of fungi, earthworms can influence fungal populations. Earthworm activity is believed to contribute to the soil's resistance to disease since it affects the microbial population and soil type through a variety of pathways.

In the stomach of an earthworm, different enzymes (of microbial or earthworm origin) are secreted in varied levels along with intestinal mucus, which can have variable effects on soil bacteria. Earthworms regulate chitinase activity, one of the most significant enzymatic activities that is crucial for controlling soil-dwelling fungal infections (Figure 2). The degradation of chitin, a crucial part of the fungal cell wall, requires chitinase (Valdivieso et al., 2004). As a result of producing phenolic acids, aqueous vermicompost extract was found to be particularly effective in inhibiting the spore germination of *Alternaria, Curvularia*, and *Helminthosporium* species (Yatoo et al., 2021). According to a study, vermicompost amendments have a suppressive impact on attacks and damages caused by psyllids, mealy bugs, aphids, jassids, and mites (Arancon et al., 2005). According to a study, *Meloidogyne incognita* populations and attacks were partially suppressed when solid vermicomposts were added to the soil (Ahamad et al., 2023).

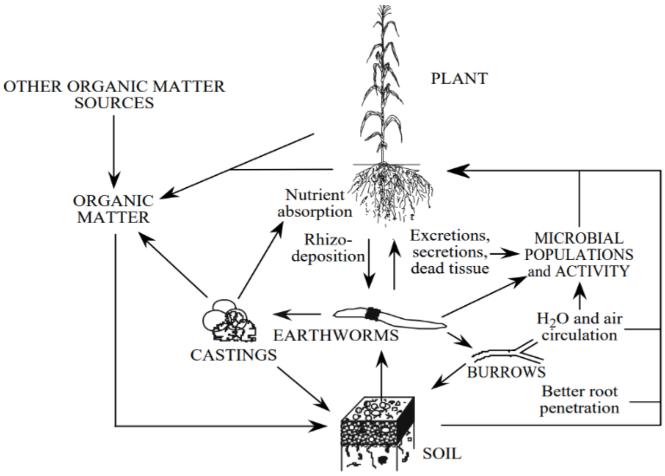

Figure 2: Activity of earthworm in soil

3.6 Vermicompost as biological soil amendment

Vermicomposting is the process of turning organic waste into vermicompost through the interaction of detritivorous earthworm species with microorganisms. This is a biooxidative, mesophilic process that significantly changes the physical, chemical, and biological properties of organic matter and has a strong impact on decomposition processes (Gomez-Brandon and Dominguez, 2014). Since organic matter acts as both the substrate and the food in the vermicomposting process, only epigeic earthworms can be utilized instead of soil. The epigeic earthworms that are most frequently used in vermicomposting and vermiculture facilities worldwide are *Eisenia andrei* and *Eisenia fetida* (Dominguez et al., 2021).

In their natural habitat, epigeic organisms face constant changes in their food sources, ambient conditions, and dangers from predators. Epigeic earthworms undergo massive population losses, sharp fluctuations in population density, and explosive increases in reproduction rate in unfavorable conditions (Monroy et al., 2006). Under these circumstances, the capacity for exponential growth and reproduction is essential. High rates of reproduction will guarantee population survival in hard environments, and the worms' ability to build cocoons may enable them to survive until conditions improve, which accounts for variations in population density. Because of favorable, stable conditions and high rates of reproduction, earthworm populations in vermicomposting facilities can reach very high densities (more than 20,000 individuals per m2) (Domínguez et al., 2016).

Vermicompost is the end result of non-thermophilic biodegradation of organic materials by combined action of earthworms and associated microbes. It is a finely divided peat-like material with low C:N ratio, high porosity, aeration, drainage, water holding capacity, and microbial activity (Arancon et al., 2005). By reducing the organic substrate's physical and chemical state through their mechanical blender function, earthworms increase the surface area that is conducive to microbial breakdown (Dominguez, 2004). Vermicast, a nutritive organic fertilizer rich in humus, macronutrients (nitrogen, phosphorus, and potassium), micronutrients, actinomycetes, beneficial soil microflora, and plant growth regulators, is excreted by earthworms after they eat soil and organic materials (Sharma et al., 2009).

The digestive system of earthworms is essential for breaking down organic materials and soil (Kiyasudeen et al., 2016). The transformation of ingested soil and organic matters into valuable products that constitute essential nutrients and active components of microbial biomass is facilitated by the activities of endosymbiotic microbes and earthworm gut enzymes, specifically cellulase, protease, chitinase acid, and phosphatase (Gomez-Brandon and Dominguez, 2014). The physical, chemical, and biological effects of vermicompost on soil fertility are covered in detail in this paper. The economics and future prospects of using organic fertilizers in agriculture are also looked at.

The nutritional status of vermicompost made with different organic wastes is as follows: organic carbon 9.15–17.98%, total nitrogen 0.5–1.5%, available phosphorus 0.1–0.3%, available potassium 0.15, calcium and magnesium 22.7–70 mg per 100 g, copper 2–9.3 ppm, zinc 5.7–11.5 ppm, and available sulfur 128–548 ppm (Kiyasudeen et al., 2016). In addition to providing nutrients and helpful bacteria to the soil, vermicompost also alters the physio-chemical characteristics of the soil, promoting improved crop growth and development. Vermicompost added to an agricultural soil at a rate of 20 t ha-1 for two years in a row has been shown to considerably improve aggregate stability and soil porosity (Deressa, 2018). Vermicompost application at a rate of 15 t ha-1 significantly ($P < 0.05$) increased soil contents of total organic carbon and nutrients, decreased soil pH, improved bulk density, total porosity, and electrical conductivity in comparison to the control plots, according to research on the effects of vermicompost on soil physio-chemical properties in tomato (*Lycopersicum esculentum* var. Super Beta) fields. Vermicompost has a favorable impact on soil characteristics, losses, and restoration; it reduces soil loss (31.2%) and improves soil quality when compared to unamended soil (Tejada et al., 2009).

3.7 Process of Vermicomposting

The primary consumers of the vermicomposting food chain are microorganisms (mostly bacteria, fungi, and ciliates) that decompose and mineralize organic waste. In the vermicomposting food chain, microorganisms include tens of thousands of different species, making them the most abundant and diverse group (Sinha et al., 2010). In addition to bacteria, earthworms and other soil invertebrates are secondary and higher-level consumers that eat the bacteria and spread them throughout the organic materials (Susilo et al., 2004). Organic stuff passes through the earthworm gizzard and is ground into a fine powder before being digested. The decomposed organic materials leaves the earthworm's body as casts as extracellular enzymes produced by endosymbiotic bacteria break down cellulose and phenolic compounds, expediting the decomposition of ingested material (Dominguez et al., 2017). Earthworms are known for their burrowing and tunneling habits. They feed on decomposing organic waste, which aerates the substrate and facilitates the flow of water, nutrients, oxygen, and bacteria. Additionally, their feeding activities increase the surface area of organic materials on which microorganisms can live. When decomposers pass away, more food is added to the food chain to absorb their place.

Earthworm activity is involved in two stages of the vermicomposting process: (a) an active phase during which the earthworms process wastes, altering their microbial composition and physical state (Lores et al., 2006); and (b) a maturation-like phase during which the earthworms move toward fresher layers of undigested waste, allowing microbes to take over the decomposition of the waste that the earthworms have processed (Domnguez, 2004). The kinds of earthworms, their population densities, and the speeds at which they eat and digest wastes all affect how long the active phase lasts. First, gut-associated activities (GAPs) are the reason earthworms have an impact on the organic waste's breakdown throughout the vermicomposting process. These processes include every alteration that microorganisms and decomposing organic debris undergo while they move through the intestines of earthworms (Blouin et al., 2013). These include the addition of sugars and other substances, alterations in the diversity and activity of microorganisms, adjustments to microfaunal populations, homogenization, and the natural processes of mucus production, digestion, assimilation, and excretion of substances like urea and ammonia, which give microorganisms an easily digestible supply of nutrients. Additionally, aiding in breakdown are endosymbiotic bacteria that are present in the stomach of earthworms. These bacteria's extracellular enzymes have the ability to break down phenolic and cellulose compounds, hastening the breakdown of food particles that have been consumed (Harrison, 1989).

The earthworm casts that are left over after GAPs are completed undergo cast-associated processes (CAPs), which are more closely related to aging, the activity of microflora and microfauna found in the substrate, and the physical alteration of the ingested materials. The GAPs are the primary source of earthworms' indirect effects on these activities. Important to note is that in vermicomposting systems, the final vermicompost is a blend of the two fractions: material that the earthworms don't eat and earthworm castings. It is during this aging process that vermicompost reaches its maximal biological properties, which promote plant development and prevent plant diseases.

3.8 Factors affecting earthworm activities

Substrate (materials): The kinds of substrate (raw materials) used in composting operations have a major impact on the quality of vermicompost. Using Eisinea fetida worms, it was discovered that cattle dung had the highest nutritional content of vermicompost (Karmegam et al., 2019).

Worm species: A variety of earthworm species are suitable for use in vermicomposting processes using municipal solid waste. The species

Eisenia foetida and Eisenia andrei are most frequently utilized due to their voracious appetites, which allow them to consume and expel organic materials at a high rate. They also live on the compost's surface, have a tendency to move horizontally through the material, avoid digging burrows, and feed on surface litter.

Particle size: The feed stock's particle size can vary greatly, which has an impact on the composting process. According to a study, smaller composting substrates often have larger surface areas and compost at a faster rate (Vengeswaran et al., 2016).

Temperature: The ideal temperature range for vermicomposting is between 15 and 25 °C (Zhang et al., 2020).

PH: According to some study, a pH of 6-7 is ideal for vermicomposting. Bacterial activity declines with decreasing pH (Khare et al., 2005).

Moisture content: a moisture content of 65-75% is ideal for vermicomposting because, in composting, bacterial activity decreases and nearly ceases at a moisture content of less than 40% (Rostami, 2011).

C/N ratio: Because bacteria need nitrogen to survive, a high C:N ratio reduces bacterial activity. Conversely, a low C:N ratio will result in the nitrogen being lost as NH_3. For active composting, a C:N ratio of 25:1 to 30:1 is optimum (Yan et al., 2015).

Levels and Balance of Nutrients: Applying the proper nutrients to the soil may help address the lack of adequate research and information on nutrition management (Chaurasia et al., 2024). Specific nutrients must be accessible in the right form, at the right concentration, and in the right ratio for compost microbes to digest them effectively. The fundamental macronutrients, such as carbon (C), nitrogen (N), phosphorus (P), and potassium (K), that microorganisms require in comparatively large amounts.

Favorable environment for vermicomposting

Vermicomposting can be used for almost all yard wastes and food wastes, with the exception of foods that are very greasy, spicy, salty, hard, or contain dairy or meat (Singh and Sinha, 2022). The main ingredients needed for vermicomposting include appropriate bedding, a food source, enough moisture, enough aeration, the right temperature, and the right PH.

3.9 How to introduce Earthworms?

Growing food that is easily accessible locally seems to be more important to people these days (Chaurasia et al., 2020). To meet demand, production methods need to be increased. The Farmers' Field School has been adapted for usage in agriculture, cattle, fisheries, and earthworm production to allow farmers to experiment and adapt individually or collectively (Chaurasia et al., 2023). Because earthworm burrows promote soil porosity, more air and water can enter the soil (Shipitalo and Le Bayon, 2004). Because of their considerable modifications to the chemical, physical, and biological aspects of the soil profile, earthworms are frequently referred to as ecosystem engineers. The activity and habitat of other creatures within the soil ecosystem may be impacted by this alteration. Tillage management, crop rotation, cover crops, manure, and the use of organic byproducts, pasture, and hay land management are among the techniques that increase Earthworm populations (Bently, 2021).

The management strategies need to be adjusted if the soil is devoid of earthworms. Initially, some of the strategies listed above should be put into practice. When the conditions are right, they accumulate swiftly. The grass is chopped and relocated from high-worm-population areas to areas free of worms. In a few years, additional colonies will emerge if the climate, soil, and organic matter are all ideal (Brown and Double, 2004). Not just the worms need to be transplanted, but the entire pasture. According to a study, it is not advised to introduce compost worms into agricultural soils. Species that thrive in compost will not live in the harsher conditions of paddock soils that dry out near the surface (Sinha et al., 2009). Earthworms are amazing little creatures that flourish in the right conditions. Therefore, before adding earthworms to garden or farming soil, the conditions for their life must be favorable. The soil in older gardens is usually compacted, poorly formed, poorly drained, and deficient in organic matter (Jim, 1998). Moreover, earthworms should not be placed directly on the soil's surface since they will be eaten by birds and destroyed by the sun. If earthworms are to be added to the soil, the following guidelines must be followed: Place earthworms into each hole and cover with dirt after adding some water and organic compost. The earthworms' continuous food source will be the organic material that is left as a cover layer, such as leaves, compost, or grass clippings.

4. Conclusion

Earthworm activity and casts help to build and preserve the soil's structure, which is essential for root development and nutrient availability. It also ensures improved aeration, water retention, drainage, and aerobic conditions. When making decisions on the management of an agroecosystem, earthworms must be taken into account due to their potential contribution to managing soil fertility. The earthworms may have an effect on soil fertility, which is crucial for boosting sustainable land use in agroecosystems and naturally degraded ecosystems. With appropriate earthworm control, crop yields could be maintained while fertilizer inputs are reduced. Through the creation of new aggregates and pores that enhance soil tilth, infiltration, aeration, and drainage, earthworms significantly contribute to the alteration of the physical structure of soils. Earthworms provide the binding substance that leads to the formation of microaggregates that are stable in water. Through soil mixing and soil burrowing, they increase soil porosity. Earthworms take involved in the cycling of nutrients, the breakdown of plant residue, and the redistribution of nutrients across the soil profile. Although chemical fertilizers and pesticides have been used extensively by farmers, earthworms can play valuable functions in their fields. Farmers need to be made fully aware of the value of earthworms so they can reap the benefits of these underground organisms in our soil.

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