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Vivek Kumar Saini

Professor, GGJ Government
College, Hisar, Haryana, India

Kanchesh

Assistant Professor, Department
of Zoology, GGJ Government
College, Hisar, Haryana, India

Raj Kumar

Associate Professor, Department
of Botany, GGJ Government
College, Hisar, Haryana, India

Deepak Kumar

District Extension Specialist,
Department of Soil Sciences,
Krishi Vigyan Kendra, Kaithal,
Haryana, India

Ravikant Verma

Assistant Professor, Department
of Zoology, Department of
Zoology, CCS HAU, Hisar,
Haryana, India

Dalip Kumar

Assistant Scientist, Department
of Entomology, CCS HAU,
Hisar, Haryana, India

Corresponding Author:

Dalip Kumar

Assistant Scientist, Department
of Entomology, CCS HAU,
Hisar, Haryana, India

Earthworms: Nature's architects of soil fertility and sustainability

Vivek Kumar Saini, Kanchesh, Raj Kumar, Deepak Kumar, Ravikant Verma and Dalip Kumar

Abstract

Earthworms, belonging to the phylum *Annelida* and class *Oligochaeta*, break down organic matter, enhance soil structure, and contribute to soil aeration and nutrient cycling. Moreover, they contribute directly and indirectly to soil fertility, organic waste management, and agricultural sustainability. Earthworm casts are rich in organic matter, nitrogen, phosphorus, and plant growth-promoting substances, including vitamins and hormones, which benefit plant growth and microbial activity in the soil. Earthworms are involved in vermiculture (the use of earthworms for waste processing) and vermicomposting (converting organic waste into nutrient-rich compost). This process is eco-friendly, reducing the reliance on chemical fertilizers and improving soil health by providing essential nutrients, enzymes, and growth hormones. Earthworms also play a crucial role in breaking down organic materials, including crop residues, sewage sludge, and industrial waste. The reproductive biology of earthworms is diverse, with many species capable of self-fertilization and rapid biomass production. The abundance of earthworms is influenced by factors such as soil temperature, moisture, pH, and organic matter content. Different earthworm species, such as *Eisenia fetida* and *Eudrilus eugeniae*, are widely used in vermiculture for waste management and soil improvement. Earthworms also positively affect crop yield by increasing soil fertility and reducing disease severity in plants. In addition to their agricultural role, earthworms are being explored for use in animal feed, protein supplements, and medicinal purposes due to their nutritional and bioactive properties. In summary, earthworms play a crucial role in maintaining soil health, managing organic waste, and promoting sustainable agriculture, thereby contributing to plant growth, soil fertility, and overall ecosystem balance.

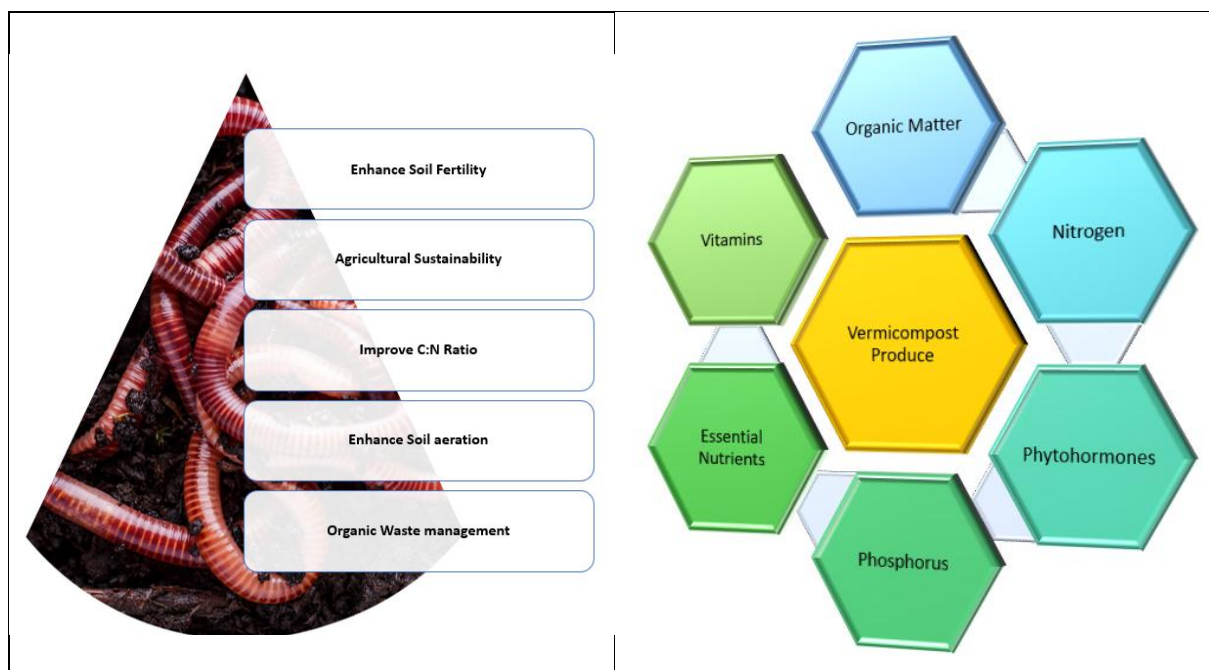
Keywords: Abundance, biology, crop yield, earthworm, season variation, soil health, vermiculture

Introduction

Earthworms are capable of transforming garbage into 'gold'. Charles Darwin described earthworms as the 'unheralded soldiers of mankind'; similarly, Aristotle called them as the 'intestine of earth', due their capability to digest a wide variety of organic materials. The soil volume, microflora and fauna influenced by earthworms is termed as "drilosphere" and the soil volume includes the external structures produced by earthworms such as surface and below ground casts, burrows, middens, diapauses chambers as well as the earthworms body surface and internal gut associated structures in contact with the soil (Brown *et al.*, 2000, Dahiya & Ravikant 2018) [5, 7].

Climate variables strongly influence the distribution, abundance, and biomass of earthworms, and changes are likely to have cascading effects on other soil organisms and wider ecosystem functions. More than 4,200 species of oligochaetes are known worldwide. Of these, 280 are Microdrili, and the remaining species belong to Megadrili (earthworms), which are classified into 10 families, comprising 240 genera. Currently, the earthworm fauna (Megadrilidae) in the Indian subcontinent comprises 509 species, classified into 67 genera and 10 families (Julka, 1993). About 68 percent of known species of earthworms in the subcontinent belong to ten endemic genera: *Drawida* (79), *Perioyx* (53), *Eutyphoeus* (43), *Megascolex* (33), *Amyntas* (33), *Plutellus* (32), *Metaphire* (26), *Hoplochaeteila* (18), *Tonoscolex* (16) and *Octochaeton* (15). The remaining 57 genera are either monospecific or represented by fewer than 10 species.

Modern agriculture's reliance on chemical fertilisers has led to environmental problems. Vermicomposting, which utilises earthworms to break down organic waste, is a cost-effective and eco-friendly solution that produces nutrient-rich compost, promoting plant growth and supporting beneficial microbes.



The ingested organic material is macerated, mixed with ingested inorganic soil material, and passed through the gut, where it is excreted as casts. The annual cast production ranges from about 133 tons dry weight ha⁻¹ in grassland to about 98 tons dry weight ha⁻¹ yr⁻¹ in woodlands. Casts have a higher amount of organic matter, total nitrogen and nitrates than the parent soil. Casts have a higher base-exchange capacity and are generally richer in total phosphorus, exchangeable potassium, manganese and calcium. The worm casts contain some provitamin D, precursors of vitamin B, free amino acids, and plant growth promoters such as auxins and cytokinins. In soil, earthworms represent the most significant component of animal biomass and are commonly referred to as 'ecosystem engineers'. Earthworms can be considered biological indicators of soil fertility, as they support a healthy population of bacteria, fungi, actinomycetes, protozoans, insects, spiders, and millipedes -all of which are essential for sustaining healthy soil. Due to these properties, earthworms are being reared for the production of vermicompost. Vast quantities of waste are produced in forests, agricultural fields, industries and cities. A majority of which can be used as a substrate in vermiculture for vermicompost production. Although the NPK value of vermicompost is typically lower than that of standard chemical fertilisers, it can promote lush plant growth by providing micro-nutrients, enzymes, vitamins, and growth hormones, as well as by improving soil texture. Vermicompost increases microbial activities in the root zone. More seed germination, heavy flowering, fruiting, resistance to pest attacks, and higher production have been reported with the use of vermicompost in various crops, trees, and forest plants (Ismail, 1997) [13].

Physical and chemical impacts of earthworms on soil

Anecic and endogeic earthworms, in association with free-living soil bacteria, constitute the drilosphere and influence the entire volume of soil through their activities, in a mutualistic association with free soil microorganisms and a few obligate, symbiotic protozoa or bacteria.

1. Bulk density: Vermicompost decreases the bulk density

of the soil after long-term use it.

- 2. Soil water holding capacity:** It increases the soil's water-holding capacity, allowing the soil to hold more water and preventing irrigated or rain-fed water from seeping deep into the water table. The soil requires a lesser amount of water compared to chemical fertilizers used in soil.
- 3. Soil organic carbon:** The use of vermicompost increases organic carbon in the soil. Vermicomposting of paper mill and dairy sludge resulted in a 1.2-1.7-fold loss of organic carbon as CO₂. In contrast to the parent material used, vermicomposts contain higher humic acid substances (Albanell *et al.*, 1988) [1].
- 4. Nutrients:** It increases the amount of some nutrients in the soil. These are essential for the plants and lead to improved crop quality and productivity. Thus, vermicomposting increases the ash content and accelerates the rate of mineralization, which is crucial for making nutrients available to plants. The observed increase in total phosphorus (TP) in vermicompost is attributed to the mineralization and mobilization of phosphorus resulting from enhanced phosphatase activity by microorganisms in the gut epithelium of the earthworms (Garg *et al.*, 2006) [10]. Vermicomposts showed a significant increase in exchangeable Ca²⁺, Mg²⁺ and K⁺ compared to fresh sludge indicating the conversion of nutrients to plant-available forms during passage through the earthworm gut (Yasir *et al.*, 2009) [33].
- 5. Humic/Fulvic acid ratio:** Vermicompost enhances the H/F ratio, resulting in improved soil health. Humic acid substances occur naturally in mature animal manure, sewage sludge, or paper-mill sludge, but vermicomposting drastically increases the rate of production and their amount, from 40-60 percent compared to traditional composting. The enhancement in humification processes is achieved through fragmentation and size reduction of organic matter, increased microbial activity within the earthworm intestine and soil, and aeration of the soil by earthworm feeding and movement

(Dominguez and Edwards, 2004) ^[8].

6. **Cation exchange capacity:** It increases the cation exchange capacity of soil, resulting in base saturation. Which intern stabilizes the soil, and pH remains constant.
7. **C/N ratio:** The use of vermicompost reduces the C/N ratio, increasing the availability of nitrogen to growing plants. C: N ratio is an indicator of the degree of decomposition. During the process of bio-oxidation, CO₂ and N are lost, with the loss of N occurring at a comparatively lower rate. A comparison of compost and vermicompost revealed that vermicompost had significantly lower C:N ratios, indicating that it underwent more intense decomposition (Lazcano *et al.*, 2008) ^[18].
8. **Electrical conductivity (EC):** EC indicates the salinity of the organic amendment. The minor production of soluble metabolites, such as ammonium, and the precipitation of dissolved salts during vermicomposting lead to lower EC values. In comparison to the parent material used, vermicomposts contain less soluble salts and a greater cation exchange capacity (Lazcano *et al.*, 2008) ^[18].
9. **pH:** Earthworm activity reduced the pH and C: N ratio in vermicompost. The Chemical analysis of vermicompost showed a lower pH, EC, organic carbon (OC), C: N ratio, nitrogen and potassium and higher amounts of total phosphorus and micronutrients in comparison to the parent material. Slightly decreased pH values of vermicompost compared to traditional compost may be attributed to the mineralisation of N and P, as well as microbial decomposition of organic materials into intermediate organic acids, fulvic acids, and humic acids (Lazcano *et al.*, 2008) ^[18], and the concomitant production of CO₂ (Garg *et al.*, 2006) ^[10].
10. **Mineralisation:** Mineralisation is the process by which the chemical compounds in organic matter decompose or oxidise into forms that plants can easily assimilate. An increase in ash content increases the rate of mineralisation, and during vermicomposting, a significant rise in ash concentration suggests that vermicomposting accelerates the rate of mineralisation. Vermicomposting of cow manure using earthworm species *E. andrei* (Atiyeh *et al.*, 2000) ^[3] and *E. foetida* favoured nitrification, resulting in the rapid conversion of ammonium-nitrogen to nitrate-nitrogen, and increased the concentration of nitrate-nitrogen to 28-fold after 17 weeks, while in conventional compost there was only a 3-fold increase (Atiyeh *et al.*, 2000) ^[3].
11. **Controlling Pollution:** Vermicomposts contain higher nutrient concentrations but are less likely to produce salinity than composts. Additionally, vermicomposts possess outstanding biological properties and have microbial populations significantly larger and more diverse compared to conventional composts. Soil supplemented with vermicompost showed better plant growth compared to soil treated with inorganic fertilisers or cattle manure (Dahiya and Ravikant, 2018) ^[7].

Vermiculture Biotechnology

In India, approximately 200 million tonnes of crop residues and 2,000 million tonnes of solid and liquid excreta from animals and humans are generated as waste annually. Besides these, there are vast quantities of domestic garbage and

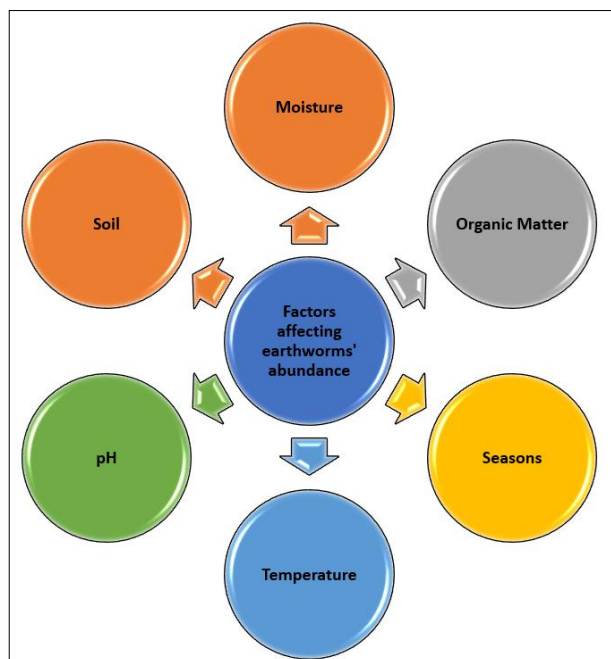
industrial waste. It is therefore essential to develop suitable technology for waste treatment through biological means, so that waste resources can be utilized to contribute to the protein bowl. Vermiculture is a technology that can be successfully used for the in-situ management and recycling of these wastes. Vermitechnology, a biotechnological approach, utilises earthworms as natural bioreactors for the effective recycling of organic waste, thereby promoting sustainable agricultural systems. Earthworms play a crucial role in decomposition, acting as aerators, crushers, mixers, degraders, and stimulators. Earthworms can process various organic wastes, including; sewage sludges and solids from wastewater, brewery wastes, paper industry wastes, and processed potato wastes, animal wastes from poultry, pigs, cattle, sheep, goats, horses, and rabbits, mushroom industry wastes and horticultural residues. Aerobic sewage sludge can be ingested by earthworms and egested as casts, during which the sludge is decomposed and stabilised approximately three times faster than non-ingested sludge. During this process, relative to non-earthworm ingested sludge, objectionable odours disappear, accompanied by a marked reduction in the population of pathogenic microorganisms. The use of earthworms in sludge management has been referred to as 'Vermistabilization'. The process of vermistabilization is due to microbial decomposition of organic matter within the gut of earthworms; thus, the undigested, released excreta of earthworms do not undergo rapid decomposition. The worm cast is a loosely packed, granular aggregate of semi-digested matter that provides energy for the establishment of various microorganisms. Some microbes found in association with the cast are responsible for deodorising excreta derived from organic waste with an obnoxious odour (Ndegwa and Thompson, 2000) ^[21]. The sludge from both agri-based industries and domestic sewage plants, which is not accepted as a soil additive directly on fields, can serve as a food source for composting earthworms and produce a higher-quality soil additive. Moreover, they can accumulate lead, cadmium, chromium, copper, nickel, mercury, and zinc. Vermicomposting, which involves earthworms in the composting process, reduces stabilisation time and produces an efficient organic pool with energy reserves. Vermicomposting of kitchen wastes reduces C:N ratio and increases total phosphorus (Padma *et al.*, 2002) ^[22]. Earthworms can be utilized to dispose of various organic wastes, including raw humus from coniferous forests, organic wastes in areca-nut and cocoa gardens, and wheat straw (Singh and Sharma, 2002) ^[30]. Vermicomposting effectively breaks down high-carbon, low-nitrogen crop residues, such as sugarcane trash, reducing C:N ratios and increasing nutrient availability (Rasal *et al.*, 2003) ^[24].

Earthworm biology

Earthworms are hermaphroditic, reproducing in various ways. They can breed only once, multiple times, or continuously. Typically, they mate with another worm, but some species can self-fertilize. Earthworms produce cocoons 1-4 days after mating, which contain 1-20 fertilised eggs. Incubation periods range from 1 to 4 weeks. Biomass production can increase 40-90 times in 3-6 months. The doubling time for the biomass of earthworms ranges from 11 to 39 days. They are composed of 76% water, with dried bodies containing approximately 1.0% carbohydrates, 11.5% lipids, and 48.0% proteins (Ismail, 1997) ^[13].

Factors affecting earthworms' abundance in soils

The population and density of earthworms in soil are affected by exposure to a multitude of environmental factors, including the quality and quantity of food, pH, moisture, temperature, amount of organic matter, type of soil, and seasons.



(i) Temperature

Temperature plays a crucial role in determining the types of earthworms found in soil and their reproductive habits. Warmer temperatures can increase cocoon production. Higher temperatures can speed up the time it takes for earthworms to reach reproductive maturity. Different earthworm species have preferred temperature ranges. Some earthworm species, such as *Eisenia fetida*, can tolerate a wide range of temperatures, from 5°C to 43°C (Reinecke *et al.*, 1992) [26].

(ii) Moisture

Soil moisture is a crucial factor in the distribution and survival of earthworms. Earthworms can lose 50-70% of their body water without dying. Most earthworms prefer a moisture level between 65-75 percent. Earthworms cannot survive in extremely dry or wets conditions, with 100% mortality occurring at moisture levels above 80%. Different earthworm species have optimal moisture levels for cocoon production, growth, and feeding activity. Some earthworms can survive underwater due to their ability to discharge excess water through their nephridia (Madge, 1969) [19].

(iii) pH

The majority of temperate climate species of earthworms typically thrive in soils with a pH between 5.0 and 7.4, and cannot survive in highly acidic or alkaline conditions, having a range of pH <5 and >9. High salt concentrations, often found in irrigated soils, can harm earthworm populations. Soil pH can affect the number of earthworms that enter a dormant state. The ideal pH conditions for the growth of earthworms are between 6.5 and 7.5. In contrast, acidic soils (pH < 5.5) significantly decrease earthworm density and diversity due to aluminium toxicity, calcium deficiency, and inhibited enzymatic activities, which affect metabolism, burrowing, and

reproduction. Thus, a pH of around 7.0 is ideal for earthworm growth and weight gain (Rayela *et al.*, 2025) [25].

(iv) Soil

Soil type affects earthworm populations. Medium-textured soils are most suitable for earthworms. Some species, such as *Aporrectodea* and *Lumbricus*, prefer soils with high clay content. Sandy or gravelly soils can lead to lower earthworm populations. In the context of soil depth, it is crucial for deep-burrowing earthworms. Insufficient aerobic soil depth can limit the establishment of deep-burrowing species (Curry and Byrne, 1996) [6].

(v) Organic matter

Organic matter provides the food base for the earthworm community, which is vitally important in determining their distribution and abundance in soils. The highest populations of earthworms are associated with compost manure and with no added organic matter. A highly significant correlation between earthworm density and soil organic carbon content has been reported across a range of sites in Georgia, U.S.A. In fourteen Egyptian soils, and in Sweden. C:N ratio and humic acid to fulvic acid ratio determined the abundance and diversity of earthworms in and around Bangalore (Hendrix *et al.*, 1992) [12].

Season variations in the activities of earthworms

Earthworms in India are typically active during the rainy season, with peak density in September and October, and lowest density in May and June. During harsh summers and winters, earthworms enter a dormant state to conserve energy. Earthworms in the Western Himalayas remain active throughout the year, with peak density during summer and winter rains, climatic factors have little influence on earthworm populations in Bangalore, but food availability is crucial, moisture stress, rather than temperature extremes, is the leading cause of seasonal earthworm mortality in temperate soils, earthworm casts show seasonal variations in phosphorus content, with a decrease from May to August in New Zealand due to lower microbial and phosphatase activity because of declining soil temperature. Summer is the least favourable season for earthworm growth, as well as for *E. fetida* and *E. eugeniae*, and vermicompost production in India (Amoji *et al.*, 2000) [2]. *Eisenia fetida* demonstrated higher tolerance to temperature ranges and performed better in both winter and summer seasons, making it a more suitable choice as a vermicomposting worm in subtropical areas of India (Saini *et al.*, 2010) [29].

Food preferences of earthworms

Earthworms are omnivores, feeding on dead organic matter, dead roots and rhizodeposition, and above-ground litter (after weathering). A nitrogen-rich diet promotes growth and reproduction. Microbial degradation increases palatability and nutrient content. Toxins, such as those found in eucalyptus or lucerne residues, can be harmful. Earthworms consume significant amounts of food, approximately 10-30% of their biomass per day, and 8-32 mg of dry plant litter per gram of wet worm weight per day. Some waste/weeds, such as water hyacinth, were found to be easily palatable, whereas rice husk was found to be unsuitable as feed for earthworms (Saini *et al.*, 2008) [28].

Vermicomposting species

Several earthworm species have potential for use in organic waste processing, but few have been widely used and researched. Commonly used species include: - *E. andrei*, *E. fetida* (tiger worms), *E. eugeniae* (African night crawler), *P. hawayana*, *L. rubellus* (red worm), *Dendrobaena veneta*. Studies have compared the growth and reproduction of these species, with *Eudrilus eugeniae* showing the fastest growth.

Some researchers advocate for using local earthworm varieties to minimize the disruption of regional biodiversity. *Allolobophora caliginosa* and *Amyntas hawayana* have also been used in vermicomposting (Brown *et al.*, 2000) [5]. *Lumbricus terrestris*, *L. polyphemus* and *Aporrectodea longa* are examples of aneceics earthworms (Kooch and Jalilvand 2008) [17].

	
<i>Eisenia andrei</i> (Source: https://tinyurl.com/9zzfpvhm)	<i>Eisenia fetida</i> (Source: https://shorturl.at/9GLCz)
	
<i>Lumbricus rubellus</i> (Source: https://tinyurl.com/22e294ac)	<i>Eisenia eugeniae</i> (Source: https://shorturl.at/9GLCz)
	
<i>Pheretima hawayana</i> (Source: https://tinyurl.com/3wuyvf8p)	<i>Dendrobaena veneta</i> (Source: https://tinyurl.com/4kddje96)
	
<i>Allolobophora caliginosa</i> (Source: https://tinyurl.com/w39s4v53)	<i>Amyntas hawayanus</i> (Source: https://tinyurl.com/5arhey7p)

Influence on crop yield

Fonte *et al.* (2023) [9] estimated that earthworms contribute to roughly 6.5% of global grain (maize, rice, wheat, barley) production and 2.3% of legume production, equivalent to over

140 million metric tons annually. Earthworm services in cropping systems have the potential to boost agricultural sustainability (Bertrand *et al.*, 2015) [4]. The presence of earthworms in soils promotes plant growth. This is due to the

presence of plant growth promoters, such as cytokinins and auxins, in earthworm casts. Earthworms also release vitamins, such as vitamin B, which stimulate plant growth. Numerous studies have reported increased crop yields and improved soil fertility due to earthworm activity; in wheat and clover, maize, mushroom, *Agaricus bisporus*, radish, *Raphanus sativus*, tomato, okra, okra and brinjal, sugarcane cucumber and carrot and paddy (Gupta *et al.*, 2002; Rafi *et al.*, 2002; Sonawane and Sabale, 2000) ^[11, 23, 31]. Earthworms have also been shown to reduce disease severity in plants; wheat root pathogens, *Gaeumannomyces graminis* and *Rhizoctonia solani*, gerbera plant diseases caused by fungi *Rhizoctonia solani*, *Phytophthora drechsleri*, and *Fusarium oxysporum* (Rodriguez *et al.*, 2000) ^[27], and tomato plants infected with *Fusarium oxysporum* (Karmegam and Daniel, 2000) ^[16]. The use of vermicompost is regarded as a sustainable practice for enhancing the biologically valued properties of fruits, such as increasing the sensory and nutritional value of the strawberry 'Senga Sengana' (Tomic *et al.*, 2025) ^[32].

Earthworms: end uses and potential

Earthworms have been explored as a protein source for animal feed. The chickens fed earthworm meal grew at rates equal to or better than those fed conventional meat meal protein supplements. Earthworms have also been used as a protein supplement for fish. Earthworms have been found to have medicinal properties, and it was reported anti-inflammatory activity of total earthworm paste on carrageenan-induced oedema in rats, efficiency similar to that of aspirin on oedema. Mira Grdiša *et al.* (2009) reported that earthworm powder can digest intravascular fibrin clots, which may be potentially helpful in treating thrombosis. Furthermore, bioluminescence has been reported in several earthworm species, including *Microscolex heteroptera*, *Pontodrilus bermudensis* and *Diplocardia longa*, and *Lampito mauritii*. Bioluminescence in earthworms is due to the presence of luciferin and luciferase locked in chloragogen cells, which burst open when secreted through dorsal pores on the body surface.

Because of their beneficial role in soil formation and soil fertility, the earthworms are called 'the friends of farmers'. Through the centuries, long before the Green Revolution, these quiet machines have been carrying out the marvellous function of ploughing the soil and fertilizing it. As awareness grows about the importance of earthworms to soil fertility and plant growth, each individual -farmer, agriculturist, horticulturist, gardener, homemaker, and children - must be educated on the valuable contribution that earthworms can and do make to life on earth (Ismail *et al.* 1992) ^[14].

Conclusion

Thus, it can be concluded that earthworms are indeed the "friends of farmers" due to their incredible contributions to soil formation and fertility. For centuries, they have been silently working beneath our feet, ploughing and fertilising the soil, long before the Green Revolution. As we become increasingly aware of the importance of earthworms, we must educate everyone-from farmers and agriculturalists to gardeners, children, and even homemakers-about the vital role these creatures play in maintaining soil fertility and promoting plant growth. By appreciating and protecting earthworms, we can work together to preserve the health of our soil, our ecosystems, and our planet as a whole.

References

1. Albanell E, Plaixats J, Cabrero T. Chemical changes during vermicomposting (*Eisenia fetida*) of sheep manure mixed with cotton industrial wastes. *Biol Fertil Soils*. 1988;6:266-9.
2. Amoji SD, Pulikeshi MB, Shagoti UM, Biradar VA. Influence of seasonal environmental factors on growth and reproduction of the epigeic earthworm, *Eisenia fetida* (Savigny 1826). *J Environ Biol*. 2000;21(1):59-63.
3. Atiyeh RM, Dominguez J, Subler S, Edwards CA. Changes in biochemical properties of cow manure during processing by earthworms (*Eisenia andrei*, Bouche) and the effects on seedling growth. *Pedobiologia*. 2000;44:709-24.
4. Bertrand M, Barot S, Blouin M, Whalen J, Oliveira T, Roger-Estrade J. Earthworm services for cropping systems: A review. *Agron Sustain Dev*. 2015;35:553-67. <https://doi.org/10.1007/s13593-014-0269-7>
5. Brown GG, Barois I, Lavelle P. Regulation of soil organic matter dynamics and microbial activity in the drilosphere and the role of interactions with other edaphic functional domains. *Eur J Soil Biol*. 2000;36:177-98.
6. Curry JP, Byrne D. The role of earthworms in straw decomposition in a winter cereal field. *Soil Biol Biochem*. 1996;29:555-8.
7. Dahiya T, Ravikant. Vermicompost to Metagenomics for Agriculture Sustainability. In: Yadav RK, Kumar S, Kumar N, Yadav P, editors. *Crop Improvement for Sustainability*. New Delhi: Daya Publishing House; 2018. p. 267-90. ISBN 978-93-5124-942-9.
8. Dominguez J, Edwards CA. Vermicomposting organic wastes: A review. In: Shakir Hanna SH, Mikhail WZA, editors. *Soil Zoology for Sustainable Development in the 21st Century*. Cairo; 2004. p. 369-95.
9. Fonte SJ, Hsieh M, Mueller ND. Earthworms contribute significantly to global food production. *Nat Commun*. 2023;14:5713.
10. Garg P, Gupta A, Satya S. Vermicomposting of different types of waste using *Eisenia foetida*: a comparative study. *Bioresour Technol*. 2006;97:391-5.
11. Gupta RK, Sihag RC, Katyal DK. Comparative study of effect of vermicompost formed by different combinations of carbonic waste on brinjal and okra. In: *Proc XI Nat Symp Environ*. 2002. p. 343-5.
12. Hendrix PF, Mueller BR, Bruce RR, Langdale GW, Parmelee RW. Abundance and distribution of earthworms in relation to landscape factors on the Georgia Piedmont, U.S.A. *Soil Biol Biochem*. 1992;24:1357-61.
13. Ismail SA. *Vermicology: The Biology of Earthworms*. Chennai: Orient Longman; 1997. p. 1-92.
14. Ismail SA, Pulandiran K, Yegnanarayan R. Anti-inflammatory activity of earthworm extracts. *Soil Biol Biochem*. 1992;24:1253-4.
15. Julka JM. *Earthworm Resources and Vermiculture*. Zoological Survey of India; 1993. p. 1-128.
16. Karmegam N, Daniel T. Effect of biodigested slurry and vermicompost on the growth and yield of cowpea, *Vigna unguiculata* (L.). *Environment and Ecology*. 2000;18(2):367-70.
17. Kooch Y, Jalilvand H. Earthworm as ecosystem engineers and the most important detritivores in forest soils. *Pak J Biol Sci*. 2008;11:819-25.

18. Lazcano C, Gomez-Brandon M, Dominguez J. Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure. *Chemosphere*. 2008;72:1013-9.
19. Madge DS. Field and laboratory studies on the activities of two species of tropical earthworms. *Pedobiologia*. 1969;9:188-214.
20. Grdiša M, Mikecin AM, Knežević N. Fibrinolytic Enzymes from Earthworms. *Dynamic Soil, Dynamic Plant*. 2009;3(Special Issue 2):61-3.
21. Ndegwa PM, Thompson SA. Effects of C-to-N ratio on vermicomposting of biosolids. *Bioresour Technol*. 2000;75:7-12.
22. Padma U, Rama Krishna Rao S, Srinivas N. Eco-friendly disposal of vegetable wastes through vermitechnology. *J Ecobiol*. 2002;14(2):155-9.
23. Rafi M, Narwadkar PR, Prabu T, Sajindranath AK. Effect of organic and inorganic fertilizers on growth and yield of tomato (*Lycopersicon esculentum* Mill.). *S Indian Hort*. 2002;50(4-6):522-6.
24. Rasal PH, Jadhav BR, Kalbhor HB. Utilization of earthworms for recycling of sugarcane trash. *J Maharashtra Agric Univ*. 2003;28(1):93-4.
25. Rayela EN, Panya FS, Andrelin A, Gecelene EC. The Impact of Soil pH on Earthworm Diversity and Abundance: A Systematic Review of Soil Acidity and its Effects on Vermicomunities. *Int J Innov Sci Res Technol*. 2025;10(4):488-94.
26. Reinecke AJ, Viljoen SA, Saayman RJ. The suitability of *Eudrilus eugeniae*, *Perionyx excavatus* and *Eisenia fetida* (Oligochaeta) for vermicomposting in southern Africa in terms of their temperature requirements. *Soil Biol Biochem*. 1992;24(12):1295-307.
27. Rodriguez Navarro JA, Zavaleta Mejia E, Sanchez Garcia P, Gonzalez Rosas H. The effect of vermicompost on plant nutrition, yield and incidence of root and crown rot of gerbera (*Gerbera jamesonii* H. Bolus). *Fitopatologia*. 2000;35(1):66-79.
28. Saini VK, Sihag RC, Sharma RC, Gahlawat SK, Gupta RK. Biodegradation of water hyacinth, sugarcane bagasse and rice husk through vermicomposting. *Int J Environ Waste Manage*. 2008;2(6):601-9.
DOI: 10.1504/ijewm.2008.021863
29. Saini VK, Sihag RC, Sharma RC, Gahlawat SK, Gupta RK. Relative efficacy of two species of earthworms in biodegradation of organic wastes under semi-arid subtropical conditions of North-West India. *World Rev Sci Technol Sustain Dev*. 2010;7(3):259-70.
30. Singh A, Sharma S. Composting of a crop residue through treatment with microorganisms and subsequent vermicomposting. *Bioresour Technol*. 2002;85:107-11.
31. Sonawane DA, Sabale RN. Effect of different sources of organic nitrogen on growth, yield and quality of Suru sugarcane. *J Maharashtra Agric Univ*. 2000;25(1):15-7.
32. Tomić J, Karaklajić-Stajić Ž, Pešaković M, Paunović SM, Rilak B, Mikulić-Petkovsek M, Hudina M, Veberić R, Kafkas NE, Ercişli S, Jakopic J. Application of vermicompost extract to improve the phytochemical composition of berry fruits. *Turk J Agric For*. 2025;49(3):530-42.
<https://doi.org/10.55730/1300-011X.3284>
33. Yasir M, Aslam Z, Kim SW, Lee SW, Jeon CO, Chung YR. Bacterial community composition and chitinase gene

diversity of vermicompost with antifungal activity. *Bioresour Technol*. 2009;100:4396-403.