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Role of earthworms in soil fertility and its impact on agriculture: A review

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Abstract
Soil fertility is defined as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Perhaps no other living organism in the soil is as important as an earthworm in helping to increase soil health. Earthworms are the most commonly occur in the soil. The activities of burrowing and feeding by earthworms have many valuable effects generally on soil quality for crop production. Earthworms increase soil aeration, infiltration, structure, nutrient cycling, water movement, and plant growth. Earthworms are one of the major decomposers of organic matter. They get their nutrition from microorganisms that live on organic matter and in soil material. When they move through the soil eating, earthworms form tubular channels or burrows. These burrows can persist for a long time in the soil. Earthworm burrows increase soil porosity which increases the amount of air and water that get into the soil. Increased porosity also lowers bulk density and increases root development. Earthworm excrement or casts increase soil fertility because it contains nitrogen, phosphorus, potassium, and magnesium. Earthworm casts also contain microorganisms which increase in abundance as organic matter is digested in their intestines. The cycling of nutrients from organic matter and the increase in microorganisms facilitates plant growth. They cast along with binding agents released by earthworms also improve soil structure and increase aggregate stability. The soil biota benefits soil productivity and contributes to the sustainable function of all ecosystems. The cycling of nutrients is a critical function that is essential to life on earth. Earthworms (EWs) are a major component of soil fauna communities in most ecosystems and comprise a large proportion of macrofauna biomass. Their activity is beneficial because it can enhance soil nutrient cycling through the rapid incorporation of detritus into mineral soils. In addition to this mixing effect, mucus production associated with water excretion in earthworm guts also enhances the activity of other beneficial soil microorganisms. This is followed by the production of organic matter. So, in the short term, a more significant effect is the concentration of large quantities of nutrients (N, P, K, and Ca) that are easily assimilable by plants in fresh cast depositions. In addition, earthworms seem to accelerate the mineralization as well as the turnover of soil organic matter. Earthworms are known also to increase nitrogen mineralization, through direct and indirect effects on the microbial community. The increased transfer of organic C and N into soil aggregates indicates the potential for earthworms to facilitate soil organic matter stabilization and accumulation in agricultural systems, and that their influence depends greatly on differences in land management practices.

Keywords: Earthworms, soil fertility, agriculture, nutrients

Introduction
Soil is the most precious natural resource and is the greatest inheritance of mankind. Our connection with soil is based upon the cultivation of soil throughout human history and led to the success of civilizations. To sustain life humans in the past were dependent on hunting and gathering of food. This rapport between humans, the earth, and the food sources confirms that the soil as the foundation of agriculture [1]. Safeguard of the soil habitat is the first measure towards sustainable management of its biological properties that decide long-term quality and productivity. Sustainable agriculture is the protection of communities, the environment, and animal welfare by producing food from plants or animals using different agricultural techniques that do not harm the ecosystem. But as a result of deforestation, overgrazing, burning crop residues, unsystematic use of agrochemicals may have helped in good getting yields, but it has the efficiency to depreciate of the soil all over the world day-by-day and reduced application of organic manures and utilization of fertile land for non-agricultural purposes, soil fertility is decreasing and further declining agricultural productivity. This, at last, led to a decline in Soil Organic Matter (SOM), soil pH, major, and minor nutrients in the soil [2].

This contemporary agricultural practice has resulted in a sharp fall in the biodiversity (above and below the ground) associated with cropland ecosystems.

Earthworms are one of the most significant soil animals; they have the potential to maintain the fertility of the soil and thus play a key role in sustainability. They are also acknowledged as farmer's friend, ecological engineers, biological indicators, intestines of the earth, and plowman of the field. Earthworms are hermaphrodites and develop slowly, except

leaf litter dwellers. Depending on the species, earthworms can live for 2-8 years and produce only generation per year with a maximum of 8-12 cocoons. Sexual maturity can be identified by the "genital belt" encircling the body (Clitellum). Except Polar Regions and deserts earthworms can be found in most of the soils and worldwide there are about 3,000 species of earthworms.

They desire medium-heavy to loamy sand soils. Heavy clay and dry sandy soils are not

good to their growth because of high and lack of moisture respectively in soils. Maximum burrowing and reproductive activity take place in the months of March-April and September-October in the temperate zone. During dry and hot days, the earthworms move to deeper layers and aestivates. The nightcrawler (*Lumbricus Terrestris*) is capable of migrating up to 20

meters. Nutrient availability increases owing to their role in organic matter decomposition and mineralization [3] and play a vital role in the enhancement of soil fertility by recuperating soil physical, chemical, and biological properties [4-6]. By activities like burrowing, casting, and mixing, besides the mineralization they play a significant role in nutrient cycling and [7-8-9] and they are termed as 'ecosystem engineers'.

Role of Earthworms in Humification

Earthworms have been scientifically studied by man right from the time of Darwin since 1881 and though different aspects such as development, physiology and ecology are studied, attention has been paid to the understanding of the relationship between earthworm and microbe only in the last two decades [10]. Soil, the major reservoir of microbes, meets the food requirement of earthworms and this has necessitated the establishment of different kinds of relationship between earthworms and microbes. Microbes form a part of food for earthworm. Microbes are proliferated in the gut and Vermicompost. Earthworms help in the distribution of microbes in soil. Microbial biomass in the worm casts was found to be high and their activity was essential for release of nutrients into the medium so as to be taken by the plants [11]. Enhanced nutrients (N, P, K, S, Ca, Mg, Fe, Zn) in the casts of earthworms, compared to the surrounding soil, was due to mineralization taking place in the gut as well as in the casts [12-13]. Decomposition and humification of biodegradable organic waste materials is predominantly carried out by microorganisms in the soil but the few recent studies have shown that earthworms play an important role in humification [14]. The composition of micro flora in the earthworm gut varies depending on the earthworm species [15]. So the microorganisms of substrates that the earthworms ingest are also equally important.

Earthworm and microbes together mineralize humified organic matter and facilitates chelating of some metal ions [16]. Earthworms have the capacity to utilize soil microbes as their food [17]. Growth and reproduction in earthworms require C and N and these were obtained from litter, grit and microbes. Even among the microbes only few were preferentially ingested while others were rejected. The role of microbes and earthworms in decompositions of organic matter and particularly, in humification is well known. With the increase in microbial population there is an increase of microbial activity and humic acid content. The actinomycetes population from all the feed substrates was found to have enhanced in the gut and cast of all the four species of earthworm indicating their role in humification since it is known that they are responsible in humus/humic acid formation [5]. They play an important role in enhancing the nutrients in the soil by mineralization through the enzymes secreted by the microbes and earthworms [18]. The increase in humic acid in vermicasts, sequesters elements like Zn, Mn and Fe from their complex forms and chelate them making them available for uptake by the plants. The diverse functional groups of humic acid are known to be very reactive with metal ions [19]. Thus the role of microbes-earthworms throws light on the flux of nutrients, particularly trace elements, between microbes, earthworms and plants.

Impact of Earthworms on Soil Ecosystem

Charles Darwin recognized and described the importance of earthworm activity in soils. Earthworms (class: Oligochaeta) comprise approximately 800 genera and 8000 species that account for up to 90% of invertebrate biomass present in soil [20]. They are ubiquitous, abundant and highly productive organisms; they are „keystone species" in soil food webs and are also known as „ecosystem engineers" in soils [80]. Earthworms influence primary soil functions and processes, such as soil structure formation, soil carbon dynamics and biogeochemical cycles [20-22]. The successful management and exploitation of earthworm bioresources has the potential to deliver significant economic and environmental benefits, especially in light of global concerns regarding sustainable land use, food security and climate change. Earthworms affect ecosystem structure and function directly by ingesting, altering and mixing organic residues and mineral soil. Through these actions, they change the structure, chemistry and biology of soil [22]. European earthworms are classified into three ecological groups based on their distinct feeding and burrowing habits. Stable isotope analysis has confirmed and refined conventional ecological classification systems [23]. Epigeic earthworms live above mineral soil, rarely form burrows and feed preferentially on plant litter. Epigeic earthworms forage below the surface soil, ingest large quantities of mineral soils and humified material, and they build ramified, predominantly horizontal, burrows. Anaerobic earthworms build permanent, vertical burrows deep into the mineral soil layer, and they come to the surface to feed on partially decomposed plant litter, manure and other organic residues. The ecological groups of some common, but not all earthworm species are clearly established. For example, *Aporrectodea caliginosa* is an epigenic and both *Lumbricus terrestris* and *Lumbricus friend* are anaerobic species [24].

Earthworms play a significant role in improving soil fertility in many ways. For example, earthworms bring the nutrients from deeper layers of soil and deposits them on the soil surface as castings, therefore neutralize leakage of nutrients. Earthworms blend soil layers and add organic matter into the soil. These amalgamations allow the distribution of the organic matter throughout the soil and make the nutrients be readily obtainable by plants and improve the fertility of the soil. Earthworms contribute by improving soil structure, incorporation, and tilling the soil, mounting humus formation, and increasing the available plant nutrients [25]. Bacteria present in the earthworm gut devastate detrimental chemicals ingested by worms and as well break down organic wastes. Plant growth regulator like Auxin is produced in castings of earthworm that stimulates the roots to grow more rapidly and much deeper. When compared to soil, Nitrogen fixation is higher in worm casts due to the occurrence of nitrogen-fixing bacteria in the earthworm gut as well as in worm casts. Nitrogenase activity in casts is moreover superior

consequently contributing to high nitrogen fixation in casts than adjoining soil [5-6-8-9].

Protection of the soil habitat is the first step towards sustainable management of its biological properties that determine long-term quality and productivity. It is generally accepted that soil biota benefits soil productivity but very little is known about the organisms that live in the soil and the functioning of the soil ecosystem. The role of earthworms in soil fertility is known since 1881, when Darwin (1809–1882) published his last scientific book entitled “The formation of vegetable mould through the action of worms with observations on their habits.’’ Since then, several studies have been undertaken to highlight the soil organism’s contribution to the sustainable function of all ecosystems [10]. Soil macrofauna, such as EWs, modify the soil and litter environment indirectly by the accumulation of their biogenic structures (casts, pellets, galleries, etc…). The cycling of nutrients is a critical ecosystem function that is essential to life on earth. Studies in the recent years have shown increasing interest in the development of productive farming systems with a high efficiency of internal resource use and thus lower input requirement and cost [26-27]. At present, there is increasing evidence that soil macroinvertebrates play a key role in SOM transformations and nutrient dynamics at different spatial and temporal scales through perturbation and the production of biogenic structures for the improvement of soil fertility and land productivity [28-29]. EWs are a major component of soil fauna communities in most natural ecosystems of the humid tropics and comprise a large proportion of macrofauna biomass [30]. In cultivated tropical soils, where organic matter is frequently related to fertility and productivity, the communities of invertebrates—especially EWs—could play an important role in (SOM) dynamics by the regulation of the mineralization and humification processes [31-22-32].

Functional Significance of Earthworms

The effects of EWs on soil biological processes and fertility level differ in ecological categories [33]. Anecic species build permanent burrows into the deep mineral layers of the soil; they drag organic matter from the soil surface into their burrows for food. Endogeic species live exclusively and build extensive nonpermanent burrows in the upper mineral layer of soil, mainly ingested mineral soil matter, and are known as “ecological engineers,’’ or “ecosystem engineers.’’ They produce physical structures through which they can modify the availability or accessibility of a resource for other organisms [80]. Epigeic species live on the soil surface, form no permanent burrows, and mainly ingest litter and humus, as well as on decaying organic matter, and do not mix organic and inorganic matter [34]. In the majority of habitats and ecosystems, it is usually a combination of these ecological categories which together or individually are responsible for maintaining the fertility of soils [35-37].

Role of Earthworms in Nutrient Availability to Soil

Earthworms play a chief part of preliminary breakdown and successive decomposition of organic matter to release and recycle of nutrients present in organic matter. Earthworms consume more surface organic matters when compared to all other soil animals jointly. They excrete these materials in the form of the cast which are rich in nutrients that are more water-soluble and are readily available to plants. Crop residues, plant litter and, partly decayed, are transported by the earthworms to the sub-surface layer from the soil surface are consumed, fragmented. These fecal materials of earthworms are called as cast, which are deposited on the soil surface inside their burrows or in the open spaces below the soil surface. Earthworms are the main life forms in the breakdown of organic matter and the conversion of major and minor mineral nutrients [5].

EWs influence the supply of nutrients through their tissues but largely through their burrowing activities; they produce aggregates and pores (i.e., biostructures) in the soil and/or on the soil surface, thus affecting its physical properties, nutrient cycling, and plant growth [38-39]. The biogenic structures constitute assemblages of organo-mineral aggregates. Their stability and the concentration of organic matter impact soil physical properties and SOM dynamics. Besides they affect some important soil ecological processes within their “functional domain [40-41]’’ where they concentrate nutrients and resources that are further exploited by soil microorganism communities [42-43]. The effect of EWs on the dynamics of organic matter varies depending on the time and space scales considered [44]. The activity of endogeic EWs in the humid tropical environment accelerates initial SOM turnover through indirect effects on soil C as determinants of microbial activity. Due to selective foraging of organic particles, gut contents are often enriched in organic matter, nutrients, and water compared with bulk soil and can foster high levels of microbial activity [45-46]. They have been reported to enhance mineralization by first fragmenting SOM and then mixing it together with mineral particles and microorganisms, and thereby creating new surfaces of contact between SOM and microorganisms [81]. In the short term, a more significant effect is the concentration of large quantities of nutrients (N, P, K, and Ca) that are easily assimilable by plants in fresh cast depositions [37]. Most of these nutrients are derived from earthworm urine and mucus [48]. In highly leached soils of humid tropics, earthworm activity is beneficial because of rapid incorporation of the detritus into the soils [49]. In addition to this mixing effect, mucus production associated with water excretion in the earthworm gut is known to enhance the activity of microorganisms. This is followed by the production of organic matter. So fresh casts show high nutrient contents. The chemical characteristics of casts differ from those of noningested soil and are rich in plant available nutrients. Upon cast deposition, microbial products, in addition to earthworm mucilages, bind soil particles and contribute to the formation of highly stable aggregates [50]. Although EWs may speed up the initial breakdown of organic residues [51], several studies have indicated that they may also stabilize SOM through its incorporation and protection in their casts [52]. Over longer periods of time, this enhanced microbial activity decreases when the casts dry, and aggregation is then reported to physically protect SOM against mineralization. Thus, C mineralization rate decreases and mineralization of SOM from casts may be blocked for several months [31]. It might become accessible again for the microflora once these are degraded into small fragments [53]. In addition EWs seem to accelerate the mineralization as well as the turnover of SOM [54]. Furthermore, studies have also indicated that organic matter in the casts, once stabilized, can maintain this stabilization for many years [55]. Nevertheless, chemical mechanisms may also contribute to the stabilization since evidence shows that the casts are held together by strong interactions between mineral soil particles and SOM that is enriched in bacterial polysaccharides and fungal hyphae [56]. Earthworm casts are enriched in organic C and N, exceeding the C and N contents of the non-ingested soil by a factor of 1.5, and 1.3, respectively. This enrichment appears in all particle-size fractions, not restricted to certain organic compound dynamics of a cultivated soil [57]. These results clearly indicate the direct involvement of EWs in providing protection of soil C in microaggregates within large macroaggregates leading to a possible long-term stabilization of soil C [58]. It has also been reported that EWs increase the incorporation of cover crop-derived C into macroaggregates, and more important, into microaggregates formed within macroaggregates. The increased transfer of organic C and N into soil aggregates indicates the potential for EWs to facilitate SOM stabilization and accumulation in agricultural systems [59].

Role of earthworms for Soil Nitrogen

Earthworms improve the organic matter mineralization in the soil and consequently increase the amount of nitrogen in the soil, as of superior nitrification in earthworm casts. In terrestrial ecosystems, a major amount of nitrogen can bypass directly through earthworm biomass. Up to 60-70 kg nitrogen per ha for one year was estimated to return to the soil in the form of dead tissue by L. Terrestris in woodland in England [5]. Earthworm tissues decompose rapidly and the nitrogen is mineralized readily. Due to the presence of nitrogen-fixing bacteria in the gut of earthworm and earthworm casts the nitrogen fixation in casts is relatively better than that in soil, which increases the activity of nitrogenase enzyme.

Role of earthworms for Soil Phosphorous

Phosphorous is a vital plant nutrient accountable for energy storage and transfer in the metabolic activities of cells. It stimulates the early vegetative growth thus, early maturity of grain crops. Though phosphorus is a necessary element for plant growth, after nitrogen it is the second most essential nutrient for plant growth [60]. Due to less solubility in water lack of mobile nature availability to the plants than other major nutrients in the soil is less. Earthworm casts hold a higher amount of available P than the soil lacking of earthworms. Due to increased phosphatase activity in the casts causes an increase in available P in earthworm casts [61]. Estimated that earthworm casts in an agroforestry system, pasture, and secondary forest could constitute 41, 38.2, and 26 kg/ha of total available P stocks respectively.

Role of Earthworms for Control of Soil-borne Pests:

Recent studies revealed that earthworm promote the growth and propagation of beneficial organisms in the soil. Earthworms distribute the insect-killing (*Steinernema sp.*) and fungi (*Beauveria bassiana*) in the soil, therefore contributing to the good natural regulation of the insect and pests. A fungal spore survives even after passing through the gut of the earthworm and can regenerate after the dropping of the earthworm. Some vertical burrowing species like Nightcrawler and blackhead worm build the permanent vertical burrows.

Factors Affecting Earthworm's Population

Many environmental factors influence action, population density, profusion, and distribution of earthworms. Soil organic matter content, type of soil, soil moisture content, the temperature of the soil, soil pH are the most important factors that regularly control the earthworm population [62]. Climatic circumstances and biotic factors strongly influence the profusion and distribution of earthworms.

a. Organic Matter

Organic matter is the most important food resource of earthworms. Many researchers found an optimistic relationship between soil organic matter content and earthworm population and biomass. Low organic matter in the soil does not promote the population, thus less number of earthworms in those particular soils [62]. Observed that increase in organic carbon content has increased the earthworm population during their work in Egyptian soil. Due to large amounts of root debris and other organic matter in pasture land has increased the earthworm population density, but the population density declined after the land is plowed and converted to the arable land. Quality of organic residues is also imperative in affecting the earthworm population density. Generally high C: N ratio residues are not preferred owing to their lower palatability by earthworms.

b. Soil Type

The soils in which earthworms live in effect their population density. Soil textures affect the earthworm populations because it influences other soil properties like moisture, nutrients, and CEC. More earthworm population density is in light and medium loam soil when compared with heavy clay, sandy and alluvial soils [5]. A relationship between the silt content of the soil and earthworm was observed [63-64]. Observed the positive relationship between clay content of soil and the population density of *A. trapezoids*, *A. osea*, and *A. caliginosa*. Amongst these species, a positive correlation with clay content was shown by *A. caliginosa*.

c. Moisture

Earthworms normally need sufficient moisture for the appropriate growth and development. 75-90% body weight of earthworms is constituted with water. Moist skin and the blood capillaries on the surface of earthworm are necessary to respire and should get an adequate amount of moisture to carry out respiratory activity [65]. The activity of earthworm is depended on the adequate availability of soil moisture. Activities of earthworms are superior in moist soil than in dry soil and therefore guard against dehydration [66]. Earthworms adopt diverse strategies to handle with arid soil conditions. Some go to deeper soil layers, few diapauses and few produce drought-resistant cocoons [67]. 60-70% moisture is most favorable for the growth and development of earthworms. Ample moisture with heavy rainfall is lethal to earthworms. Since anaerobic conditions are created by too much moisture and they occupy the place of dissolved oxygen to survive earthworms move to the soil surface where they are exposed to damaging ultra-violet radiation and predation.

d. Temperature

Growth, metabolism, reproduction, and respiration of earthworms are the activities which are affected by temperature. The increase of temperature above the critical point may be fatal for earthworms. Earthworms can tolerate chilly and damp conditions better than hot and arid conditions [66]. The tolerance rate of earthworms may change from species to species. Fluctuation in temperatures will affect the fecundity, cocoon duration, time for incubation, and the growth beginning with hatching to sexual maturity in earthworms [5]. At higher temperature Cocoons tend to hatch sooner and for growth of the indigenous population of Lumbricidae in Europe 10-150C is the optimal temperature [68].

e. Soil pH

Earthworms are very susceptible to soil pH. The pH will affect the distribution of the earthworms in many species [7]. Reported that the neutral soil pH is optimal by most species of the earthworms, but they can tolerate up to 5.0-8.0 pH. Variation in soil pH may decline the population density of earthworms [62]. Reported an increase in mortality of earthworm species at pH value below 5. Reduced earthworm activity was observed at high soil pH, above 9.

Significance of Gut Microbiota

Differences in the digestion and assimilation processes in earthworms suggest the possible existence of ecological group-specific gut micro biota [28]. Although the microbial profile of the gut content of soil depends on feed resources [69]. It is not a coincidental combination of the microorganisms present in soil [14]. The evolutionary relationship between earthworm burrowing and feeding habits and the gut microbial community has not been defined as gut-associated microbial communities [70]. They can expect the microbial profile of the gut to be an important determinant of earthworm metabolism. Diet, host anatomy and phylogeny have been shown to influence the composition of micro biota within the gut of carnivores, herbivores and omnivores, including humans and primates [71]. However, there is no information available regarding the comparative microbial community composition in different earthworm ecological groups or the association between gut micro biota biodiversity and ecological groups. This study analyzed the relationship between bacterial community tightly associated with the gut wall and earthworm ecological groups and environment. Bacteria were discriminated using automated ribosomal intergenic spacer analysis (ARISA) of the intergenic spacer (IGS) region between bacterial 16S-23S rDNA genes. Earthworms and soil collected from the field and a microcosm study (where earthworms were subjected to different food resources) were analyzed to determine the relationship between gut wall bacterial community and both earthworm ecological groups and species. Earthworm and soil samples from three geographical locations, incorporating field sites under different management practices and agricultural regimes, were analyzed to determine the relative impact of habitat and species on gut wall-associated bacterial diversity.

Gut Wall Ecosystem

The common species of earthworm ecological groups foster the development of distinct gut wall-associated bacterial communities and that the relative abundance of specific bacteria within the gut wall, including Proteobacteria, Firmicutes and an actinobacterium, is ecological group specific. Food resources and habitat can cause bacterial community shifts at the gut wall, but the magnitude of these shifts does not obscure the delineation between ecological group-specific gut wall bacterial communities. Analysis of more genera of earthworms determines whether genus mirrors ecological groups with respect to differences in gut wall-associated micro biota. However, it is clear from this study that ecological group outweighed habitat and that habitat outweighed species with respect to its influence on bacterial communities tightly associated with the gut wall of earthworms. A study showed that grassland soil nematodes harbor feeding group-specific gut bacterial diversity [70].

The tenacity of earthworms for specific food types reflects their metabolic capacity. Physical, physiological and biochemical properties dictate the metabolic capacity of the earthworm gut [20]. In mammals, gut morphology significantly influences bacterial community compositions [71]. Although the complexity of the earthworm gut is relatively low, ecological groups do differ in their gut morphology and gut transit time for passage of ingested material. For example, anaerobic earthworms have a longer gut, a simple typhlosole with less folding, a longer gut transit time and sharper gut contractions, as compared with Endogenic earthworm [72]. Differences in gut morphology, folding and contractions most likely contribute to the establishment of distinct bacterial communities across the earthworm ecological groups. Bacteria make a significant contribution to the biochemical activity in the gut of organisms and it is likely that differences in diet among earthworm ecological groups lead to the establishment of different bacterial communities [73]. The development of the gut wall-associated bacterial community in some earthworm species is a process of natural selection. The strongest determinant for selection of the gut wall associated bacterial community is in the order of Ecological Group > Habitat > Species. All members of the gut wall-associated bacteria are detected in soil and their relative abundances on gut walls were influenced by the quality of the habitat, and also on the availability of food resources; this has significant implications. The perturbation of the soil ecosystem has an impact on earthworm gut wall-associated bacterial community composition and hence on earthworm ecology and functioning. Having determined that commonly found members of earthworm ecological groups house distinct gut wall-associated bacterial communities, the challenge is to determine the functional significance of the bacteria, particularly those whose relative abundance is ecological group dependent. Understanding the composition and function of the earthworm gut wall associated bacterial community will help designing appropriate management practices for sustainable agriculture and other land uses. By facilitating the formation of an appropriate gut wall-associated bacterial community, they will maximize our ability to exploit benefits of earthworms for sustainability of soil ecosystem at local, regional and global scale.

1. **Effective Agricultural practices to improve the earthworm population**

Avoid rigorous soil tillage and minimize the use of plow:

- Usage of plough and fast rotating implement should be used only if it is necessary, because 25% of loss caused due to plowing and more than 75% loss of earthworm can be caused by the use of rotating implements.
- Due to high earthworm fertilization activity during the periods of March-April and September- November the intensive tillage should be avoided.
- As the majority of earthworms are in hibernation activity during dry and cold conditions the impact of tillage will be at a minimal level.
- Compaction of soil can be reduced by the usage of on-plows and shallow plows.
- Conservation tillage reduces the risk of soil compaction, for good infiltration, reducing water runoff and evaporation, hence improves the water retention capacity.

2. **Minimizing the soil compaction by less ground pressure**

- Heavier the tillage equipment more the soil compaction which will harm
  the earthworm population and other insects. Hence select the machinery which is light in weight.
- To avoid soil compaction, tillage activity should be done only when the soil is dry or in well-drained soils.

- **Diversified crop rotation to enhance earthworm population:** Diversified cropping with enduring and deep-rooted plants that are rich in clover or green manure crops are selected.

3. **Diversified crop residues are essential for the improvement of the earthworm population.**

- Incorporation of cereal residues by plowing in the soil usually increases the earthworm population by adding up of the higher amount of organic matter than a leguminous crop which decomposes rapidly and leaves less organic matter [5].

4. **Fertilizer application concerning to soil properties and plant requirement**

The quantity and the kind of fertilizer both can affect the earthworm population.

- A soil which is well balanced and adequate as per fertilizer requirement is good for both earthworms and crops.
- It's better to use the slightly rotten compost than the ripen compost to promote the earthworm population.
- Organic residues may cause anaerobic reactions if the residues are buried at deeper depth which may be detrimental to the earthworms, so it is better to bury them in shallow depths.
- To ensure the neutral soil PH should be applied regularly based on the requirement of the soil by maintaining the soil pH not below 5.5 is important.

EWs are known also to increase nitrogen mineralization, through direct and indirect effects on the microbial community. Studies by Bhadauria T *et al*. on the role of EWs in the nitrogen cycling during the cropping phase of shifting agriculture in North East India showed that the total soil nitrogen made available for plants through the activity of EWs was higher than the total input of nitrogen to the soil through the addition of slashed vegetation, inorganic and organic manure, recycled crop residues, and weeds [74]. An important role of EWs is the dramatic increase in soil pH as observed through the studies in shifting agroecosystem in North East India, in a sedentary terrace agroecosystem in central Himalayas, and in intensive agroecosystem in Indo-Gangetic plains. This increases microbial activity and N fixation in the soil, so that nitrogen in the worm cast may be due at least in part to this rather than to concentration by gain worms. Nitrogen mineralization by microflora is also quite intense in the earthworm gut and continues for several hours in fresh casts, [75-58], respectively, by incorporating organic matter into the soil and or by grazing the bacterial community. EWs have been found to either enhance or decrease bacterial biomass [76], and to stimulate bacterial activity [77].

The influence of EWs on N cycling, however, appears also to be largely determined by cropping system type and the fertilizer applied (mineral versus organic). Various experimental studies suggest that EWs have potentially negative consequences on fertilizer-N retention studies [78]. The earthworm species and species interactions present in the system also effect nitrogen mineralization and crop production. This may result in enhanced nitrogen immobilization or mineralization depending on species characteristics and substrate quality. The review thus highlights the important effects that EWs have on C and N cycling processes in agroecosystems and that their influence depends greatly on differences in management practices. Further the EWs can also increase nutrient availability in systems with reduced human influence and low nutrient status, that is, no tillage, reduced mineral fertilizer use, and low organic matter content. The role of EWs in improving soil fertility is ancient knowledge which is now better explained by scientific results emerging from different studies. This is an important field of study where the research is directly linked to the social welfare [79]. Every involved step requires appropriate protocols and reproducible results. This is a feedback mechanism where the technology adopted in the fields is further improved in the laboratories based on the feedback received from the technology adopters so as to provide more convincing information to technology adopters.

Summary

Earthworms are referred to as friends of farmers considering their crucial role in the ecosystem there is a need to utilize them in the agroecosystem management. They improve the soil fertility in many ways by bringing the nutrients from the deeper layers of the soil which can be easily absorbed by the plants. They also help in aeration, good root penetration, and further improving the soil fertility and crop productivity. But with the modern technologies and the human greed for better yield obtained from indiscriminate use of chemical fertilizers is degrading the ecosystem as well as agroecosystem. The degradation of soil fertility is therefore a result of a decrease in the earthworm population because of the environmental factors. Good earthworm management will maintain crop yields and also reduce the fertilizer input of farmers. Usage of sufficient organic manures despite of chemical fertilizers with fewer disturbances of soil enhances the activity of the earthworms in the soil for improving and maintaining soil health and fertility.

Considering the potential contribution of earthworms to soil fertility management, there is the need to consider them in agroecosystem management decisions. The earthworms can specifically affect soil fertility that may be of great importance to increase sustainable land use in naturally degraded ecosystems as well as agroecosystems. Proper earthworm management may sustain crop yields whilst fertilizer inputs could be reduced. Since farming can involve many soil disturbing activities, the understanding of the biology and ecology of earthworms will help devise management strategies that may impact soil biota and crop performance. Hence, this review article was prepared by collecting the ideas that improve earthworm activity and soil fertility.

Future Research Needs

Most of the studies conducted to assess the role of earthworm casting in nutrient cycling and soil structure are related to surface casting species, and only a few have dealt with casts deposited under field conditions. To reach a better understanding of the ecological impact of in-soil casts, the assessment of nutrient dynamics in earthworm burrows and on the effect of in-soil casts on plant growth would be of immense help. For below-ground casting earthworm species, the ecological impact of their below-ground casts is likely to be as important as their surface casts in relation with nutrient availability, especially for biological management of degraded and disturbed ecosystems. Therefore, more research is needed to be done in this area to complete our knowledge of the role of earthworms in nutrient dynamics so as to evolve strategies for better soil management techniques.

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