Earthworms: 'Soil and Ecosystem Engineers' – a Review

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Abstract Earthworms can alter the soil environment by changing soil properties. They have great potentiality to enhance soil physical properties like bulk density, infiltrability, hydraulic conductivity, porosity, aggregate stability. Due to this ability they are only species which plays significant role in pedoturbation. Similarly, their role in nutrient cycling and organic matter breakdown is of unique interest. Earthworm cast fortified with the microbial population. Increasing microbial activity in soil, increases the nutrient mineralization and release. Earthworm activity enhances root distribution so that immobile macro nutrients like phosphorous and other micronutrients, which are absorbed by plant through root interception, are easily available to the plants. Hence, earthworms play important role in bioturbation, they are considered as 'soil engineer.' However, their activity differs with the agroecosystems. Their population density is more in reduced tillage system than conventional tillage system, aerobic condition than anaerobic conditions, grasslands than forest. Low population of earthworm was found in dry land agroecosystems. But earthworm presence in extreme environment is not studied well yet. So, this paper was reviewed to explore the role of earthworm as soil and ecosystem engineer. This was already established fact but main aim of this paper is to collect the related information and conclude the future research prospects to strengthen the earthworm role as soil and ecosystem engineer.

Keywords: earthworm, bioturbation, pedogenesis, nutrient cycling, soil and ecosystem engineer

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1. Introduction

Earthworms are the docile creatures of soil ecology. Earthworms are also called the 'ecosystem engineers’ (Lavelle et al., 1997; Hale et al., 2005) as they have great potentiality to change soils and plant communities. Earthworms are macro fauna commonly found in the tilled soils, grasslands and other agro ecosystem. About 800 genera and 8000 species of earthworm are recorded in the world (Edward, 2004) which belongs to the order Oligochaeta. Many authors agree on the beneficial role of earthworm in the soil but few reviewers and researchers point to the negative effects (Agarwal et al., 1958; Rose and wood, 1980) of introduced earthworm in the soil fertility and crop production. Barios et al. (1987) reported the positive effects of earthworms in nutrient mineralization and release of nutrients in the soil system.

Three major types of earthworms found in the soil ecosystem; which are classified as a) Epigeic, b) Endogoeic and c) Anecic (Bouche, 1972). Epigeic species feeds on the upper surface while endogoeic made the permanent deep burrows. Anecic species resides near subsurface soil region. They have their own morphology and have own feeding system. Epigeic species mostly feed on plant debris. So, they are mostly responsible for breaking down complex organic residues and mineralize nutrients. However, endogoeic species mostly feed soil and built permanent burrows. There is more microbial activity around the burrows.

Earthworm density is lower in the dry land agroecosystems (Johnson-Mynard, 2007). On comparing with the reduced tillage and conventional tillage; earthworm population density was found more in the reduced tillage system (Edward and lofty, 1982; Wardle, 1995; Emmerling, 2001). In reduced tillage system lower manipulation of soil creates less soil disturbance (Chan, 2001), less physical injury of earthworm (Lee, 1985) and more food supply & congenial soil conditions (Kladivko, 2001). Hence, there is more presence of earthworm in no till system.

In aerobic ecosystem, earthworms perform well but under anaerobic ecosystem (paddy field) their activity is limiting (Zorn et. al., 2008; Schutz et. al., 2008) that consequently effect their role as ecosystem engineer. However, certain researches focus on the importance of earthworm, either introduced or native, in increasing rice productivity (Chutinan et. al., 2010). Gates (1972) reported that, only one earthworm species Drawida beddardi remains active in flooded condition. So, there is necessity of more research to verify earthworm as soil and ecosystem engineer at various agro-ecosystem.

1.1. Earthworm and Drilosphere Concept

Drilosphere is that part of soil which is influenced by the earthworm activity. It a fraction of soil that contains...
earthworm burrows and casts which is highly populated with microbial load. In Figure 1, for the formation of the biogenic structures, major roles were played by the Ecosystem engineers i.e. earthworm in association with microflora. For the digestion of complex organic molecules earthworms occupies the major fraction. It shows that, earthworm activity within the drilosphere enhances microbial activity (microflora) along with the other biological components.

Figure 1. Soil Ecosystem engineers relation with other soil biological components. (Modified from Lavelle, 1997)

There is high degree of relationship exist between the microorganisms (fungi, actinomycetes, bacteria), micro-, meso-, and macro invertebrates (Protozoa, mites, springtails, millipedes, isopods, nematodes) with the anecic species of earthworm (Brown, 1995; Anderson and Bohlen, 1998; Maraun et. al. 1999) which are the chief biological creatures of drilosphere which involve in breaking down of complex organic molecules to form several biogenic structures. However, endogeic species have more influence with the microbial community rather than anecic species (Bhatnagar, 1975) because anecic species built permanent burrow system in soil (about 2 m depth) which is an important route of root growth activity and microbial dispersal (Ehlers et. al. 1983). Earthworm activity (preferentially endogeic species) is more around the rhizospheric region of plant roots (0.5 mm thin soil layer attached to plant root surface) which are rich in microorganisms (James and Seastedt, 1986; Rovira et. al., 1987; Robertson et. al. 1994; Hirth et. al. 1998).

1.2. Earthworm and Pedogenesis

Soil formation i.e. Pedogenesis is not only the physico-chemical process, it also involves the several biological phenomenon. Earthworm as macro fauna inhabitant of soil plays an important role in Pedogenesis. Earthworm helps to form the soil structure (Figure 2) by mineralizing and humifying the plant debris and organic residues. On the basis of morphology, habitat, and earthworm types; earthworms involve in the pedologic processes (Lavelle, 1988). The cast of the earthworm, fortified with mucilaginous secretion, helps in aggregate formation and stability (Shipitalo and Protz, 1988; Marinissen and Dexter, 1990) which is the foundation for soil structure formation. Water stable biogenic structures i.e. organo-mineral aggregates are found in the earthworm presence soil (Jouquet et. al. 2004; Bossuyt et. al., 2005; Jouquet et. al., 2009).

Figure 2. Earthworms role in Pedogenesis acting at various scale (modified from Lavelle et. al., 2004)

Earthworm have positive role in soil structure formation (Mackay and Kladivko, 1985; Ketterings et. al., 1997). Earthworms help to enhance the soil penetrability and reduce the soil compaction (Scott Russell, 1977) and enhance root distribution (Stockdill and Cossens, 1966; Ellis et. al., 1977; Edwards and Lofty, 1978). Earthworms are also called 'natural tillers' because they increase aeration porosity (Knight et. al., 1992), infiltration capacity (Stockdill, 1966) and hydraulic conductivity (Ehlers, 1975; Johnson-Maynard et. al., 2002), water stable aggregates (Zeigler and Zech, 1992; Ketterlings et. al., 1992) of soil, decrease bulk density (Johnson-Maynard et. al., 2007). Whatever the types of earthworm, their role of bioturbation is significant and, hence, in Pedogenesis

1.3. Earthworm and Organic Matter & Nutrient Cycling

Figure 3. Influence of earthworm on soil physical and biological properties enhancing the nutrient supply in the soil. (Modified from Syers and Springett, 1984)

Earthworms enhance the fertility of soil by enhancing the soil physical, chemical and biological properties of soil. The role of earthworm in maintaining the soil fertility has been long discussed from Darwin (1881) up to this
date. Several review papers and articles regarding beneficial effects of earthworm (Edwards and Lofty, 1982; Lee, 1985) have been published. A simple conceptual framework of the earthworm effects on soil properties to enhance soil nutrient cycling is presented in Figure 3. Plant growth was affected by earthworm (Lal, 1999; Scheu, 2003) by enhancing the nutrient availability to the plants. The major feed source of earthworm in the soil is organic matter. So they play a very important role in organic matter cycling (Satchel, 1958). During the digestion process, soil mixes with the organic matter inside the gut of earthworms which then is incorporated into the soil profile. Loss of nitrate and ammonium nitrogen will be six to eight times less in the earthworm incorporated system (Sharpley et al., 1979).

Mobility of some nutrients such as phosphorous (less than 1 mm) which is absorbed by the plants through root interception mechanism (Tisdale et al., 1985) is poor in the soil. Increasing root distribution and penetration more in the soil enhances the uptake of phosphorous as it provides more surface area for root interception. Root distribution and penetrability was increased by earthworm activity (Edwards and Lofty, 1978).

Earthworms near the rhizosphere of wheat plants were found to be abundant (Rovira et al., 1987) and similarly in maize (Binet et al., 1997) and in sugarcane (Spain et al., 1990). A functional interaction of earthworm with the microorganisms and plant growth is illustrated in Figure 4.

![Figure 4](image)

**Figure 4.** Beneficial and harmful microbes interact with earthworm and affect crop yield (modified from Edwards and Fletcher, 1988)

2. Conclusion

Presence of earthworm in different ecosystem differs with their types and habitat. There are lots of research papers found on the role of earthworm on soil properties. In a normal soil ecosystem their role was significant to bring changes in soil environment with their activity. But there is still some sort of gap present to find out earthworms performance in extreme environmental condition. There is certain contradiction found on the positive and negative role of earthworm in soil productivity. Very few paper talks about negative role of earthworm. Hence, further study is necessary to explore the role of earthworm in extreme conditions like, permanent water stagnation, puddled field condition. Still there is scope of earthworm study on the basis of temperature regime of soil.

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The impact of earthworms on soil dynamics can be defined as changes in physical characteristics, microbial activity, and nutrient chemical conditions. However, these processes are interconnected to an extent while attempting to separate them can prove difficult. In a review and synthesis of the target and nontarget effects of applied biocides, Ingham [51] reports that in addition to earthworms, carbofuran reduces populations of beetles, weevils, assorted borers, nematodes (of various functional groups), springtails, and Rhizobium (at high concentration applications) and can alter fungal dominance 1 year after application. However, earthworms as ecological engineers play an important role in their environment. The positive effects of earthworms on plant production have been extensively documented as well as their effects on heavy metal solubility and availability. The interactions between heavy metals and earthworms depend on the earthworm species, the metal, and the physical and chemical properties of the soil. Earthworms have an effect on metal speciation in soils, changing the bioaccessibility and bioavailability of the metals for other organisms, such as plants. Blouin M et al (2013) A review of earthworm impact on soil function and ecosystem services. Eur J Soil Sci 64:161-182 Google Scholar. Bohlen PJ et al (2002) Indirect effects of earthworms on microbial assimilation of labile carbon. Thus, the earthworms are claimed as 'ecosystem engineers' of soil [2]. These ecological engineers bear a high potential to influence the quality and microenvironment of soil. In a review [2], the author highlighted the determining role of earthworm in pedogenesis, nutrient cycling, and fertility enhancement in soil. The earthworm efficiently transforms biodegradable organic waste materials into a vermicast - a bioprocessed end product rich in nutrients [3].

Introductory Chapter: Earthworms - The Ecological Engineers of Soil. Chapter. Full-text available. Earthworms play an essential role in the soil ecosystem, feeding on organic residue and recycling nutrients back into soil; increasing rainwater absorption through soil aeration, soil loosening, and soil tunneling; and promoting flowering, root development, and overall plant health by fertilizing the soil with a unique waste product called castings. (A) increasing rainwater absorption through soil aeration, soil loosening, and soil tunneling; and promoting. (B) they increase rainwater absorption through soil aeration, soil loosening, and soil tunneling; and promote. (C) they increase rainwater