

# Role of Earthworms in Soil Fertility and Factors Affecting Their Population Dynamics: A Review

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## Abstract

*Earthworms mix soil layers and incorporate organic matter into the soil. This mixing allows the dispersion of the organic matter through the soil and makes the nutrients held in it available to plants and improves the fertility of the soil. Earthworms when present improve the soil physical, chemical and biological properties and acts as soil conditioner. They do so by fragmentation, aeration, breakdown of organic matter in soil and release plant available nutrients and also due to secretion of plant growth hormones, their role in nitrogen fixation, carbon dynamics, and phosphorous dynamics. But their population in soil is threatened by a number of soil and environmental factors. Agricultural practices like heavy tillage operation and application of chemical fertilizers also contribute in the reduction of earthworms in soil. Change in land use due to increase in human population brings change in the system and make it unsuitable for the growth and development of earthworms. This review was thus made to understand the factors that affect the population dynamics of earthworms in any system so that appropriate environmental condition and earthworm friendly agricultural practices can be adopted for optimum activity of earthworms and for fertile and productive soil.*

**Key words:** Earthworms; soil fertility; nutrients; soil properties; population dynamics

## Introduction

Soil is the greatest heritage of mankind and is the most valuable natural resource. Humans were historically dependent on hunting and gathering of food to sustain life. Our

relationship with soil is based upon cultivation of soil throughout human history and led to the success of civilizations. This relationship between humans, the earth and the food sources upholds the soil as the foundation of agriculture (Parikh and James, 2012). But there is a scenario of declining agricultural productivity due to decrease in soil fertility as a result of deforestation, overgrazing, burning crop residues, indiscriminate application of agrochemicals and reduced application of organic manures and other land use changes such as use of fertile land for non-agricultural purpose, land fragmentation, use of marginalized areas and slope lands for cultivation. This ultimately causes a decline in SOM, major and minor nutrients in the soil and soil pH (Alfred *et al.*, 2008). Therefore, our efforts should be directed in conservation of soil and soil fertility, while increasing agricultural productivity and food security. Thus, maintenance of soil physicochemical and biological properties and the socio-economic environment is crucial for production through sustainable use of the available land and other resources. Earthworms increase nutrient availability due to their role in organic matter decomposition and mineralization (Brown *et al.*, 2004) and play an important role in soil fertility enhancement by improving soil physical, chemical and biological properties (Aina, 1984; Edwards and Bohlen, 1996 and Abdul Rida and Bouché, 1997). They play role in nutrient cycling and dynamics along with mineralization due to their burrowing, casting and mixing actions (Lee, 1985; Edwards and Bohlen, 1996; McLean and Parkinson, 2000 and Bohlen *et al.*, 2004a-c) and they have been called as 'ecosystem engineers'.

There are several factors affecting earthworm population dynamics positively and/or negatively. Soil organic matter (SOM), total soil nitrogen, available phosphorous, available potassium, soil texture and pH frequently regulated the earthworm population. Disturbances in natural system alter the habitat of soil biota and in some cases make the habitat unfavorable for them. The increased use of chemical fertilizers and chemical pesticides creates a threat to soil organisms. Soil cultivation may cause mechanical damage to earthworms or expose them to predation. In some cases, the machinery may create adverse conditions for earthworm growth, development and fecundity (Nuutinen, 1992 and Paoletti, 1999). Some of the soil and environmental factors are responsible for the death of our friends, earthworms, which work in the soil from thousands of years and make our soil fertile and productive. It is very important to understand about the effects of these factors on earthworms for sustainable management of soil for optimum growth and development of soil organisms for sustained production and optimum output. Therefore, sufficient literatures were reviewed for understanding the roles of earthworms in soil fertility and factors affecting their population dynamics.

### **Methodology**

An extensive review was done to collect information about the role of earthworms in soil fertility and factors affecting their population dynamics. The collected information was arranged systematically for easy understanding of the subject matter. The literature was collected from journal articles, proceedings, reports, books, thesis works, online internet etc.

### **Technological finding: a review**

#### ***Role of earthworms in soil fertility***

Earthworms play an important role to improve soil fertility in a variety of ways. For example, earthworms bring up the nutrients from deep in the soil and deposit them on the soil surface as castings, hence counteract leaching of nutrients. Earthworms mix soil

layers and incorporate organic matter into the soil. This mixing allows the dispersion of the organic matter through the soil and makes the nutrients held in it available to plants and improves the fertility of the soil. Earthworms contribute to soil fertility by improving soil structure, mixing and tilling the soil, increasing humus formation and increasing the available plant nutrients (Ramsay and Hill, 1978). Earthworms eat a large amount of litter but only a small fraction of digested material (5-10%) is assimilated by the earthworms and the rest are excreted out in the form of earthworm cast which are rich in NPK, micronutrients and beneficial soil microbes (Bhawalkar and Bhawalkar, 1993 and Bhat and Khambata, 1994). Bacteria in the earthworm gut destroy harmful chemicals ingested by worms and also break down organic wastes. Auxin is a plant growth regulator produced in earthworm castings that stimulate roots to grow faster and deeper. Nitrogen fixation in casts is comparatively higher than in soil due to presence of nitrogen fixing bacteria in the earthworm gut and also in earthworm casts. Nitrogenase activity in casts is also higher thus contributing to higher nitrogen fixation in casts than surrounding soil (Edwards and Bohlen, 1996 and Ranch, 2006).

### **Earthworms and soil organic matter**

Earthworms play a major role in initial breakdown and subsequent decomposition of organic matter and release and recycling of nutrients contained in organic matter. In fact, more surface organic matters may be consumed by earthworms than all other soil animals together. Earthworms excrete these materials in the form of cast that is rich in nutrients and more water-soluble and available to plants. Plant litters and crop residues, partially decomposed, from the soil surface are consumed, fragmented and transported by the earthworms to the sub-surface layer. Instead the fecal material of earthworms, known as its cast, is deposited on the soil surface in their burrows or in the free space below the soil surface. Earthworms are key organism in organic matter breakdown

and transformation of major and minor mineral nutrients (Edwards and Bohlen, 1996).

### **Earthworms and soil nitrogen**

Earthworms increase the mineralization of organic matter in soil and thus add to the amount of nitrogen in soil from the mineralization because of enhanced nitrification in earthworm casts. A significant amount of nitrogen can pass directly through earthworm biomass in terrestrial ecosystems. Satchell (1967, quoted in Edwards and Bohlen, 1996) estimated that about 60-70 kg nitrogen ha<sup>-1</sup>yr<sup>-1</sup> was returned to the soil in the dead tissue of *L. terrestris* in woodland in England. Earthworm tissues decompose readily and the nitrogen in the earthworm tissue turns over rapidly and the nitrogen is mineralized readily. Satchell (1967, quoted in Edwards and Bohlen, 1996) also reported that in 10-20 days 70 percent of the nitrogen in earthworm tissue is mineralized. Nitrogen fixation in casts is comparatively greater than that in soil due to the presence of nitrogen-fixing bacteria in the gut of earthworm and in earthworm casts which increases nitrogenase activity.

### **Earthworms and soil phosphorus**

Phosphorus is an important plant nutrient responsible for energy storage and transfer in the metabolic reaction of living cells. It also stimulates the early vegetative growth and is responsible for early maturity of grain crops. Though P is an essential element for plant growth, it is the second most limiting nutrient for plant growth after nitrogen (Vance *et al.*, 2000; Hinsinger, 2001 and Vacance, 2001). P is less soluble in water and comparatively less mobile and available to the plants than other major nutrients in the soil, especially nitrogen. Soil pH, ion-antagonism and the concentration of metals (Ca, Fe, Al) that can co-precipitate with P ions are responsible for weak availability of P in soil (Hinsinger, 2001).

Earthworm casts contain higher amount of available P than surrounding soil without earthworms. Nuutinen *et al.* (1998) observed

a positive association between earthworms and soil P content and this emphasized the importance of earthworm activities in P cycling. This increase in available P in earthworm casts may be due to increased phosphatase activity in the casts (Satchell, 1967). But Kuczak *et al.* (2006) in a review explained that the increase in P in earthworm casts may be due to: (a) a higher pH in the intestinal tract of earthworms (6.8 and 6 for anterior and posterior part and 5-5.4 for the soil respectively) (Barois and Lavelle, 1986), (b) carboxyl groups released from carbohydrate compounds by mucus secreted in earthworm gut in a huge amount can block and compete for P sorbing places and in turn increase soluble P, (c) increased microbial activity during digestion process. Ingestion and thorough mixing of soil in the intestinal tract of earthworm can modify the chemical form of P along with its concentration. The rates of release of inorganic phosphorus in the casts were about four times faster than that in the surface soil (Sharpley and Syers, 1976). Kuczak *et al.* (2006) estimated that earthworm casts could constitute 41, 38.2 and 26 kg ha<sup>-1</sup> of total available P stocks in agroforestry system, pasture and secondary forest respectively.

### ***Factors affecting earthworm's population dynamics***

#### **Environmental factors**

Several environmental factors affect activity, population density, abundance and distribution of earthworms. Soil organic matter content, soil type, soil moisture content, soil temperature, soil pH are most critical factors that frequently regulate the earthworm population (Wood, 1972; Lee, 1985 and Werner *et al.*, 2005). Climatic conditions and biotic factors strongly affect abundance and distribution of earthworms (Werner *et al.*, 2005).

#### ***Organic matter***

Organic matter is the major food source of earthworms. Many researchers found a positive correlation between soil organic matter content and earthworm number and

biomass. A soil with low organic matter content cannot support higher number of earthworms (Edwards and Bohlen, 1996). Schmidt *et al.* (2004) observed increased earthworm number with increased organic carbon content in their work in Egyptian soil. Large numbers of earthworms in pasture land are due to large amounts of dead roots and other organic matter (Stehouwer *et al.*, 1994 and Edwards and Bohlen, 1996). But when pasture is plowed and converted to arable land there will be gradual decrease in organic matter leading to a decrease in earthworm count. The quality of organic residues is also important affecting the earthworm abundance and diversity. Generally earthworms do not prefer residues with high C:N ratio owing to their lower palatability.

### **Soil type**

The soil environments in which earthworms inhabit affect their abundance and distribution. Soil texture affects earthworm populations since it influences other soil properties like moisture, nutrients and CEC (Edwards and Bohlen, 1996). Higher numbers of earthworms are found in light and medium loam soil than in heavy clay, sandy and alluvial soils (Edwards and Bohlen, 1996). A correlation between silt content of the soil and earthworm abundance was reported by Hendrix *et al.* (1992). A weak positive correlation was found by Baker *et al.* (1992) between clay content of soil and the abundance of *A. trapezoides*, *A. rosea*, and *A. caliginosa*. Among these species *A. caliginosa* showed the strongest positive correlation with clay content.

### **Moisture**

Earthworms generally require adequate moisture for their proper growth and development. Water constitutes about 75-90% body weight of earthworms. They respire through a moist skin and the blood capillaries on the surface should get enough moisture to perform respiratory activity (Eckert and Randal, 1988). Earthworm activity is determined by adequately available soil moisture. Earthworm's activities are higher in

moist soil than in dry soil and thus protection against desiccation is required (Mary, 1982 and Kretzschmar and Bruchou, 1991). The moisture requirement varies among species and different regions of the world (Edward and Bohlen, 1996). Earthworms adopted different strategies to cope with dry soil conditions. Some move to lower soil layers, some diapause and some produce drought resistant cocoons (Kretzschmar and Bruchou, 1991). For growth and development of earthworms 60-70% moisture is optimum. Adequate moisture accompanied with heavy rainfall is fatal to earthworms. Because excessive moisture takes the place of dissolved oxygen and creates anaerobic conditions, earthworms are forced to move to the soil surface where they are subjected to damaging by ultra-violet radiation and predation.

### **Temperature**

Temperature greatly affects the growth, metabolism, activity, reproduction and respiration of earthworms. Higher temperatures above the critical limit for survival can kill earthworms. Cold and moist conditions can be better tolerated by earthworms than hot and dry conditions (Edwards and Bohlen, 1996). Temperature tolerances and preferences of earthworms vary from species to species. Temperature also affects fecundity, duration of cocoon incubation time and the growth period from hatching to sexual maturity in earthworms (Holmastrup *et al.*, 1991). Cocoons tend to hatch sooner at higher temperature. 10-15<sup>0</sup>C is the optimal temperature for growth of the indigenous population of Lumbricidae in Europe (Lee, 1985). According to Satchell (1967) night soil temperature not exceeding 10.5<sup>0</sup>C is the most suitable condition for earthworm activities.

### **Soil pH**

Earthworms are very sensitive to soil pH. Abundance, distribution and species composition of earthworms are affected by soil pH. According to Edwards and Bohlen (1996) a neutral soil pH is preferred by most



species of the earthworms, but pH of 5.0 to 8.0 can be tolerated by them. Low or high pH is generally unfavorable for many species of earthworms and increase or decrease in soil pH may cause decline in earthworm count. Werner *et al.* (2005) reported a decline in earthworm species at pH value below 5. They also reported reduced earthworm activity at too high soil pH, above 9. Many workers observed a decline in the number of earthworms with a small drop in pH from neutral (Edwards and Bohlen, 1996). But there are some earthworm species that can occur in soils with low pH value, even at pH 3.5 (Edwards, 1988). Rivero-Hernandez (1991) stated that earthworms prefer soil with a pH from 7.0 to 8.0.

### **Effects agricultural practices and chemicals on earthworm's population dynamics**

Earthworms play an important role in providing soil fertility and improving soil physical properties, especially that of soil structure. Earthworms are both a measure of soil fertility and an indicator of soil management practices. So the use of earthworms for our benefit depends not only on the knowledge about their activities but also on our awareness that how our activities affect their abundance and distribution. Cultivation, cropping, fertilizers and chemicals are four main practices that influence earthworm populations (Edwards and lofty, 1977; Edwards and Bohlen, 1996; and Kladivko, 2003).

#### ***The effects of cultivation***

Many researchers observed more earthworms in natural ecosystems than in ploughed agricultural systems (Edward and Bohlen, 1996 and Kladivko, 2003). Scientists agreed that grasslands contain more earthworms than arable land. Soil disturbance has a negative effect on earthworm population; an important positive relationship was observed between earthworm abundance and no-tillage system and also with soil C content (Brown *et al.*, 2004). Cultivation decreases the number of earthworm progressively with time. This

decrease in number of earthworm when cultivated may be due to loss of top insulating layer, loss of food as soil organic matter decreases with subsequent cultivation and predation by birds when exposed by cultivation. Some earthworm researchers have considered that the differences in earthworm number between grassland and cultivated land is mainly due to mechanical damage during cultivation. But some researchers do not accept mechanical damage as a primary cause of decrease in earthworm number (Edwards and Bohlen, 1996 and Smeaton *et al.*, 2003), because cultivation has little effect on deep burrowing earthworms and earthworms have high regeneration power so they can recover easily. Consequently, some authors believe that the decrease is mainly due to predation.

#### ***The effects of cropping***

Type of crop on the land influences the earthworm population. Abundance and distribution of earthworms depend on the amount of crop residues and their quality in different agro-ecosystems (Hendrix *et al.*, 1992). Crop rotation leaves sufficient amount of residues to the soil and thus enhances earthworm population. Crop residues with low C:N ratio is palatable and is preferred by most earthworm species than residues having higher C:N ratio. Generally leguminous residues are more palatable having low C:N ratio and preferred by earthworms than residues with high C:N ratio such as mature grass and grain species. But legumes such as soybean that produce fewer residues reduce the number of earthworm by limiting the quantity of food (Smith *et al.*, 2008). Ploughing and incorporating cereal residues in the soil generally increase earthworm number by addition of higher quantity of organic matter than leguminous crop which decompose quickly and leave less organic matter (Edwards, 1984). Hopp and Hopkins (1946) pointed out that alfalfa-grass cropped plots contained more earthworms than lespedenza grass-cropped plot. Probably, this is because of the quantity of the plant material returned to the soil after harvest (Edwards and

Bohlen, 1996). Edwards and Bohlen (1996) reported more earthworms under continuous maize than under continuous soybean and even more under continuous winter cereals.

### ***The effects of fertilizers***

The effects of inorganic fertilizers on earthworm vary from site to site. Inorganic fertilizers are both beneficial and harmful to earthworms (Lee, 1985). Inorganic fertilizers when applied change the soil pH and also change the form and quantity of vegetation produced. Chemical fertilizers reduce earthworm count by reducing pH on the one hand but on the another hand they enhances earthworm count by increasing vegetative production which in turn increases the amount of residues returned to the soil (Duiker and Stehouwer, 2007). Edwards and Bohlen (1996) reported four-fold increase in earthworm number with application of superphosphate and lime to pasture. Lime is also beneficial because many species of earthworm tend to avoid acidic soil condition or they need calcium (Hale and Host, 2005). Gerard and Hay (1997) reported decreased numbers of earthworms in grass plots with the application of superphosphate fertilizers. Application of nitrogenous fertilizers may also favor buildup of a large number of earthworms. Edwards and Lofty (1977) reported increased earthworm numbers with application of large amounts of nitro chalk to many pastures due to increased grass production.

Organic fertilizers increase earthworm number more than chemical fertilizers for the same N increment in arable land. Organic manures favor more build-up of earthworms because they serve as additional food source for earthworms and they make the crop residues having high C:N ratio more palatable to earthworms.

### ***The effects of chemicals***

Pesticides, heavy metals, poly chlorinated biphenyls and acid precipitations are agricultural chemicals that reach soils. These chemicals when present in the soil affect earthworm abundance and distribution

directly by interfering with earthworm fecundity, reducing their activity, decreasing their count and finally causing earthworm mortality. Effects of pesticides on earthworms depend on the type and application rate of pesticides, age and species of earthworms and the prevailing environmental conditions. Application of contact pesticides that are broad spectrum in action kills most of the earthworms even those residing deep in the soil (Edwards and Bohlen, 1996 and Duiker and Stehouwer, 2007).

### **Conclusions**

Earthworms are farmer's friend because they mix the upper and lower soil layers and doing so they bring the nutrients from lower soil layer to the layer of root penetration from where plants can easily absorb the nutrients. They improve soil fertility in a numbers of ways and thus are important for higher soil productivity. But there are some environmental factors that threat their population density and distribution. Faulty agricultural practices like conventional tillage and indiscriminate use of chemical fertilizers and pesticides are also responsible for decrease in earthworm numbers in any system. The decline in soil fertility is thus a result of decrease in earthworm number due to several factors. These factors are described systematically in this review. But there are factors that enhance earthworm numbers and soil fertility. Maintenance of soil fertility for sustained production needs approaches that increase earthworm's activity. Therefore, this review was made to collect ideas about factors that enhance earthworm activity and soil fertility. Input of sufficient organic manures instead of chemical fertilizers with minimal disturbances in soil can be adopted for optimum activity of earthworms in soil for healthy and fertile soil.

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