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Earthworms as an Ecosystem Engineers in Urban Landscape

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ABSTRACT: The preservation of healthy soil is essential to the existence of the global ecosystem. Earthworms are an important soil taxon as ecosystem engineers, providing a variety of crucial ecosystem functions and services. Even though the majority of earthworms reside at or below the soil's surface, other factors can affect their habitat selection. Climate and vegetation are two important factors. In general, earthworms don't thrive in extremely cold or dry environments. The native forests and tussock grasslands are home to earthworms, while introduced species are more frequently found in cultivated soils like pasture, cropland, and lawns. The position of the species within its habitat, or niche, is a more precise way to describe where earthworms live. The geographic range and ecological function that make up a species' niche are both important. Earthworms take advantage of conditions that are most favorable to their survival by occupying a particular niche. Although all earthworms have common characteristics, features like size, pigmentation (skin colour) and quickness of movement reflect which niche different species occupy. Soil-dwelling earthworms fall into three main niche groupings: compost and soil-surface dwellers (epigeic), top-soil dwellers (endogeic) and deep-burrowing subsoil dwellers (anecic). Engineered soils provide numerous ecosystem services in urban landscapes, such as water regulation and plant growth. They are constructed to optimize soil physicochemical properties but their biological properties are given little consideration. In particular, earthworm communities may be highly impacted by soil engineering processes and soil isolation caused by asphalted surfaces separating soils, and in particular roadside soils, from pseudo-natural soils. Engineering processes define the soil's ability to host earthworms, and soil isolation defines soil ability to be colonized from nearby environments. Considering the contribution of earthworms to the provision of ecosystem services, both soil engineering and soil isolation should be taken into account to optimize their development in landscapes.

Keywords: Earthworm, Landscaping, Ecosystem, Soil engineering, Bioindicator.

INTRODUCTION

The preservation of healthy soil is essential to the existence of the global ecosystem. The global ecosystem, which includes the soil, air, marine, and forest ecosystems as interconnected matrices where each system is interdependent and complementary to one another, is inextricably linked to soil health in addition to providing services to the soil ecosystem. Both the flora and fauna of the soil play a vital role in maintaining the health of the soil. Increasing soil fertility is a significant challenge when we focus on agriculture instead of soil because soil is the only sustainable platform where the atmosphere, hydrosphere, and biosphere interact to support plant growth. Over the years we have taken many progressive steps in agriculture and major thrust of soil biological research has been assigned to soil flora which includes bacteria, fungi, actinomycetes, mycorrhiza etc. But soil fauna *viz.*, nematodes, collembolans, mites, and earthworms are the most commonly studied ones. Amongst the fauna, earthworms are the well-known burrowing animals due to their exceptional ability to churn the soil.

It helps in formation of aggregates, nutrient enrichment as well as mobilization by decomposition of dead organic residue, thus stabilizing the soil ecosystem. They digest soil or organic matter 300 times of their body mass and form a large amount of worm cast transforming one form of humified organic matter to another. Hence, they are rightly named as 'Soil engineers' (Babu Ojha and Devkota 2014). It has long been understood that both plants and animals play an important part in how ecosystems work, and naturalists and biologists are aware that organisms can influence the physical and chemical processes that take place in ecosystems. The term "ecosystem engineering" was chosen and accepted by the majority of scientists because these non-trophic relationships between the biota and their environment did not fall under the typical categories of ecological interactions (Berke, 2010). In terrestrial ecosystems, soil biodiversity supports a number of concurrent functions, with ecosystem engineers acting as the primary movers. At various spatial and temporal scales, soil macro-invertebrates are essential for the transformation of soil organic matter and the dynamics of nutrients. This review aims at overviewing the key role endorsed by earthworms through their landscaping services.

EARTHWORMS

The largest terrestrial faunal biomass is made up of earthworms, which typically prefer moist environments with moderate temperatures (Bardgett, 2005). In many ecosystems, earthworm populations make up 8% of all soil biomass and between 40 and 90 percent of soil macrofaunal biomass. In order to more effectively exploit their edaphoclimatic environment, earthworms develop different reproductive strategies (r and K), depending on a variety of variables, including plant cover, soil properties (soil texture, soil organic matter content), as well as internal population processes, such as reproduction rates and dispersal mode (Bullinger-Weber *et al.,* 2012).

At a local level, earthworm populations are typically found in clusters in relation to the location of food sources, either as a result of surface litterfall or close to living roots that release more carbon into the soil than the soil around them. Based on their behaviour, ecological niches and feeding ecology, earthworms are generally split into three main ecological categories. i) epigeics inhabit and feed in the upper organic soil layers, and produce organic castings but rarely ingest soil particles, ii) endogeics are geophageous species that live in the upper organo-mineral soil layers and construct horizontal burrows, consuming mineral soil materials with soil organic matter in various degrees of decomposition and, iii) anecics take advantages of both the surface litter as a source of food they drag into their galleries, and the deepest mineral soil as a refuge in which they dig burrows; they usually produce surface-casts.

According to latitude, altitude, human management, as well as abundance, biomass, density, and seasonal activity, earthworm communities' species composition varies at the landscape scale (Mariotte *et al.,* 2016). Additionally, because earthworm populations are controlled in a density-dependent manner, interactions between and within species may have a significant impact on species responses and, in turn, the structure and operation of lumbricid communities, with further implications for soil processes (Uvarov, 2009).

Still there is scope of earthworm study on the basis of temperature regime of soil. Earthworm bioturbation activity depends on both soil temperature (Uvarov *et al.,* 2011), and moisture (Kanianska *et al.,* 2016). Until now, most of the studies on earthworm communities have been conducted on mature soils and describe interactions between biota and structure in cultivated and anthropogenic soils.

Recently, a novel study was established that sits at the intersection of a lab experiment and the environment. Using an experimental rhizotron for 7 years, Potvin and Lilleskov (2017) observed the non-destructively in-situ dynamics of earthworm activity. They demonstrated in pine and hardwood sites that there is a strong relationship between introduced earthworm activity and vertical distribution, earthworm species, and seasonal variations in soil temperature. As a result, the endogeic *Aporrectodea caliginosa* is more likely to enter an aestivation period than the anecic Lumbricus terrestris, which typically stays active throughout the winter. However, during the summer, when soil temperatures were at their highest and soil moisture levels were at their lowest for the year, all earthworm activity significantly decreased.

There hasn't been much investigation into earthworm behavior in the wild. Even in these young soils and in the early stages of topsoil formation under willow forests, water stable macro-aggregates caused by earthworm activities have been seen in floodplains where sediment deposits regularly occur relative to flood events. Changes in earthworm communities frequently correspond to gradients in alluvial dynamics (Fournier *et al.,* 2015). Fluvisols appear to produce the best conditions for earthworm abundance and biomass because of their high and consistent moisture conditions.

MUCUS AND GUT

Mucus, a group of polysaccharide compounds made by earthworms, is secreted at the body's surface and in the gut's anterior region. A common temperate endogeic species' daily production of cutaneous mucus was calculated to be between 0.2% and 0.5% of the worm's carbon content. The amount of mucus in the earthworm's anterior gut ranges from 4% to more than 30% of the dry matter content; however, the earthworm's posterior half gut is devoid of mucus, raising the issue of whether or not this enriched C-source can be recycled.

Recent research has demonstrated that *Aporrectodea caliginosa* mucus promotes the activation of microorganisms, which improves the mineralization and humification of plant residues. As a result, during the incredibly brief period (between 1 hour and 1 day) of a gut transit, earthworm digestion results in the mineralization of 5% to 20% of organic matter on average. The passage of soil through the lumbricid earthworms' digestive tract is said to take 2 to 24 hours. Additionally, the amount of soil in the intestinal tract of earthworms may be astonishing. It was calculated that the earthworm population's guts could hold about 1L of soil for every square meter of temperate soil (2000 individuals m^{-2}). Around 4 to 10% of the soil passes annually through earthworms' gut that is the equivalent to several hundred tons of dry soil (Lavelle *et al.,* 2016).

The earthworm gut has been described as a "mutualistic digestive system" in which the exoenzymes produced by ingested microorganisms enhance the degradation of complex organic matter during their passage through the gut and thus enhance the capacity of the worm to assimilate nutrients.

Additionally, the earthworm gut is a mobile anoxic microzone in aerated soils and is abundant in easily broken-down organic compounds, many of which seem to be byproducts of microbial fermentation produced by ingested microbes during gut passage. These authors also emphasized the significance of the earthworm's mutualistic digestive system for metabolic processes related to denitrification in the gut, particularly the release of nitrogenous gases by bacteria in the earthworm's intestines that can grow in anoxic conditions.

As a result, digestion processes in the intestinal tract of earthworms are closely related to biogeochemical cycles, which indicate the breakdown of organic matter in soil, including carbon, nitrogen, and phosphorous. Thus, the addition of mucus enriched in carbon, nitrogen, and phosphorus during the gut transit qualifies earthworms as chemical engineers.

EARTHWORM CASTS

The earthworm functions as a living bioreactor that modifies and reshapes mineral and organic particles. Earthworm gut transit time likely influences the degree of microaggregate disruption in the initial stages before being reshaped into larger aggregates, depending on ecological categories. Through the production of casts within the soil and on the surface (often referred to as surface-casts or middens when particularly enriched in organic matter debris), which are often called surface-casts or middens, earthworms can process up to 25% of the Ah horizon in a year and can therefore be significant aggregate-forming agents. Other authors also found that water-stable biogenic structures, i.e., organo-mineral aggregates, are found in the soil colonized by earthworms (Jouquet *et al.*, 2009). Most of the studies focused on surface-casts whose amount of production may reach a mean of 40-ton ha^{-1} $yr.^{-1}$. In grassland in Luxembourg, a total amount of 195.6 tons ha^{-1} casts was observed, 58% from endogeic earthworms and 42% from anecics.[13] Discriminating surface-casts from casts observed into the soil profile, they represent 44.4 ton ha^{-1} and 151.2 ton ha^{-1}, respectively (Zangerle *et al.,* 2016).

EARTHWORM BURROWS

As soil macropores, earthworm burrows serve this purpose, and as they move through the soil, earthworms increase porosity. This decreases soil density, which in turn improves soil aeration, infiltration, and water-holding capacity, particularly in casts and burrow linings. In order to ensure effective hydraulic conductivity, the quantity of burrows, their length, diameter, and, most importantly, their connectivity, must all be considered. The ecological groups of earthworms as well as site-specific factors like soil texture, temperature, water content, and topography have a significant impact on the earthworms' burrow systems. Some species, like Lumbricus terrestris, dig long-lasting burrows in the ground where they can spend many years. In temperate region soils, estimates of the number of burrows range from 100 to 800 m^{-2}. The majority of burrows are between 30 and 40 cm deep in the soil, and the length, diameter, and branching of each vary depending on the species of earthworm.

Another benefit of earthworm burrows is the concentration of soil organic matter within them as a result of earthworms, particularly the anecic Lumbricus terrestris, moving detrital resources from the soil surface. Burrow linings are therefore more enriched in organic matter than the soil that is not consumed (Le Bayon *et al.*, 2009).

Over the past 20 years, new methods that are more advanced and dependable have emerged to study earthworm burrow size and three-dimensional orientation in greater depth.Two different burrow forms were discovered in soil cores taken from a permanent pasture under natural circumstances: i) a single, small-diameter burrow that was likely dug by endogeic species like *Aporrectodea caliginosa* and *Octolasion tyrtaeum lacteum*, and ii) Burrows made by the anecics *Lumbricus terrestris* and *Aporrectodea giardi* that are long and continuous and have a large diameter. The two types of burrows occupied different amounts of soil over time, which was attributed to variations in the burrowing behaviors and burrowing longevity of the earthworm species at the study site. Understanding soil structuring processes and nutrient fluxes requires research on whether or not burrows persist in soils.

ENGINEERING PROCESSES

As previously stated, ecosystem engineers alter biotic or abiotic materials in their environment to create or modify habitats, thereby regulating the resources available to other species. The authors' explicit exclusion of trophic interactions from ecosystem engineering in the form of tissue provision or consumption is an intriguing aspect, though. Processes that are dissimilatory or assimilatory (such as the assimilation or decomposition of organic compounds) are also not included.

Though they all contribute to building the physical framework of ecosystem, termites, ants, and other feces would not be included in engineering processes if the definition were strictly followed. This is because earthworm defecation clearly involves assimilation and dissimilation. In light of this, Berke contends that defining ecosystem engineering as independent of or unrelated to assimilation and dissimilation may result in ambiguous interpretation. Berke suggest then that when assimilatory and dissimilatory processes alter the availability of non-tissue resources, they should be included under the umbrella of ecosystem engineering (Babu Ojha and Devkota 2014). We totally agree with this point of view and we also suggest that engineering processes also occur directly in the intestinal tract of earthworms, these latter acting as alive bioreactors.

So, based on the functional classification of ecosystem engineers proposed by Berke, earthworms can be considered as i) structural engineers; ii) chemical engineers; iii) bioturbators. The structural function refers to both aggregates and burrows formation and the chemical one to earthworm involvement in nutrient cycling. Earthworms are also recognized as one of the three top bioturbators in soils, together with ants and termites. As a result, soils are homogenized at the soil profile scale. By contrast, the hotspots resulting from earthworm activities, where nutrient availability and microbial activity are higher compared to the soil matrix, contribute to increase the spatial heterogeneity of soils. The bioturbation has also an impact on the biological composition of soil. Earthworms are known to impact soil seed banks mainly by dispersing and feeding on seeds. Indeed, earthworms play a role in seed transport and translocation into deep soil layers, by accelerating or decelerating seed germination and seedling establishment (Clause *et al.*, 2015).

EARTHWORMS IN SOIL ECOSYSTEMS

Earthworms naturally occur in most terrestrial ecosystems around the globe. They constantly structure the soils that they live in. Their burrowing activities mix the soil and improve the flow of air and water through the underground world. By eating dead organic material from the soil surface, dragging it down into the soil, digesting it, and then leaving their droppings, they redistribute nutrients throughout the soil. These activities affect other life below and above the ground. The altered air, water, and nutrient availability changes how other organisms can use their resources, where they can live, and how well they can grow and reproduce. Through these activities, earthworms influence bacteria, fungi, springtails, mites, beetles, plants, and even animals that live above the soil surface, such as aphids. Consequently, earthworms are very important soil organisms[1] with impacts beyond the belowground world. This is fine in areas where the other organisms are used to having earthworms around, but it can become problematic where they are not used to these squishy neighbors.

ECOSYSTEM AND EARTHWORM

Earthworms live in the soil. Although different earthworm species have different burrowing habits, eating habits, and ways of life. As a result, different earthworm species exhibit different ecological functions. The three types of species are epigeic, endogeic, and anecic. Epigeic earthworms are small (5–15 cm in length at maturity), brightly colored, and feed and live on the surface layer of rich litter. They do not dig burrows. The comminution process of litter and organic matter at the soil surface by epigeic species contributes to nutrient transformation and the stimulation of microorganism activity. Anecic species are colored on the dorsal side and frequently have large bodies (15–20 cm) because they live in subvertical burrows in mineral soil, feed on fresh litter from surface soil, and bring it into the soil profile. Anecic earthworms can tunnel up to 1-2 meters into the soil's deeper layers. By digging vertical burrows and increasing macroporosities, aeration, and water infiltration into the deeper soil, their feeding activity alters the soil's structure. Anecic burrow entrances, also known as "middens," are typically crowned with fragments of plant litter and are surrounded by a mound of cast material. By incorporating surface litter into the soil profile, anecic earthworms also have an impact on the rate of litter breakdown and nutrient cycling. Live earthworms are endogeic. Endogeic earthworms are referred to as soil feeders because they live and eat in the soil. They are crucial in the formation of soil aggregates.

Endogeic species typically lack pigmentation and have a body size of 5 to 10 cm. As a result of their activity, a network of horizontally branching burrows is formed, increasing porosity and allowing nutrients from their feces to escape. Pontoscolex corethrurus, an endogeic earthworm, was introduced to agroforestry mesocosms, increasing mean weight diameter and C and N storage in significant macroaggregates (>2000 µm) (Keith and Robinson 2012). The physical, chemical, and biological characteristics of soil ecosystems inhabited by epigeic, endogeic, and anecic earthworms are superior to those of ecosystems inhabited by only one or two levels of earthworm functional groups. Additionally, the provision of various earthworm functional groups in soil enhances ecosystem services.

In addition to being divided into functional groups, earthworms can also be divided into native and exotic species based on biogeography. Earthworms that are native to the area or site evolve there. In contrast to species that have been introduced by human activity, such earthworm species typically live in a single region. Exotic or introduced earthworm species are those that have been intentionally or unintentionally moved to places where they do not naturally occur. Most studies have concentrated on this particular group of earthworms.

Earthworms are most active in moist soil conditions. The earthworm community structure is controlled by the nutrient content of soil and the amount of seasonal rainfall.

Decomposing organic waste serves as earthworms' primary food source. Earthworms favor organic food that has been decomposed and is larger than 50 m. Earthworms prefer to live close to the source of the food source due to their limited mobility. The quantity, quality, and timing of litter inputs to the soil system have a significant impact on the population density and distribution of earthworms in forest ecosystems. The abundance of secondary compounds in litter, such as polyphenols, has an impact on the number of earthworms in tropical forests.

Earthworms have been called “ecosystem engineers.” They are capable of modifying their physical environment by mixing soil layers from the bottom to the top and vice versa incorporating organic matter into the soil and producing biogenic structures. This way, earthworms change the structure of the soil. Different types of earthworms' functional groups can create horizontal and vertical tunnels, which can be quite deep in soil. These tunnels form pores that facilitate oxygen and carbon dioxide exchange, and allow water penetration into the soil. Thus, water, gas and solute transfer processes and soil water holding capacity improve. Earthworms' burrows serve as soil macro-porosities. Soil porosity is crucial property because it determines: (1) rate of water infiltration, (2) water holding capacity, (3) the drainage of water excess, (4) soil moisture, and (5) the exchange rate of CO_2 from soil to atmosphere and vice versa. The disruption of earthworm diversity impedes water infiltration into the soil thus resulting in increased surface run-off, erosion, flooding, and drought.

Earthworm casts (earthworms' feces) are also crucial to the structure of soils. Earthworm activity has a positive impact on the formation of soil structure, through the improvement of infiltration rate, water absorption, and soil resistance against the erosive of rainfall and surface run-off. Earthworms make continuous channels from the soil surface to the deeper layers, so that water can infiltrate quickly into the subsoil. Therefore, the soil with higher earthworm activity has better infiltration rate than soil without or with small earthworm community. Hence, earthworm activity reduces the risks of run-off and water logging.

In addition to these indirect advantages, earthworms also directly benefit humans, being for example a food source for fish (and used as a fish bait), and being part of vermicomposting. Some Amerindian communities in South America utilize earthworm as a source of seasonal food and an essential source of protein in their diet (Keith and Robinson 2012). Earthworms, like all other organisms, have certain advantages and disadvantages. Some species of earthworms were reported to have adverse impacts on soil structure. Small-sized endogeic earthworms, a “de-compacting species,” eat castings produced by large-sized endogeic earthworms (compacting species), so that the organic matter content of the casting decreased. Casting with lower organic matter will be broken easily by raindrops, resulting the compacted soil. Fresh earthworm casting is soft and fragile, and vulnerable to raindrops, but it becomes harder, and more resistant to water and wind erosion with time. Effect of compacting species on soil structure is strongly influenced by the presence of organic debris on the soil surface. However, in the soil with high organic matter content or soil mulched with legumes, earthworms enhance soil macro-aggregate development. *P. corethrurus* invaded a pasture in Central Amazonia, and produced an excessive amount of unstable large cast. This cast formed 5 cm impermeable crust inhibiting plant growth. Soils with low organic matter and low earthworm diversity and abundance s tend to be more sensitive to erosion than soils with high earthworm population and diversity. Management of soil organic matter is keys factor affecting the ecosystem services performed by earthworms.

A. Epigeic

Epigeic earthworms are found in environments with a lot of organic matter. They eat dung, decaying plant roots, and leaf litter while living at or close to the soil's surface. These earthworms don't dig long-term tunnels. Pigmented skin is more common in epigeic species. They can blend in with the surrounding foliage thanks to the pigmentation. Additionally, it shields them from UV rays. Because they are exposed to predators and need to move quickly due to their close proximity to the ground surface, earthworms have muscles that are strong and thick relative to their length. In heavily grazed paddocks, their proximity to the ground also makes them susceptible to stock treading. The majority of epigeic species are small (1–18 cm in length). Introduced tiger worm Eisenia fetida, which cannot survive in soil, is one example of an epigeic earthworm that prefers to live in compost and under logs and dung. Most native species dwell in the detritus of forests (Suthar, 2009).

B. Endogeic

The most prevalent type of earthworm in New Zealand is called an endogeic one. The soil's top 20 cm are their preferred habitat. Endogeic earthworms consume a significant amount of soil and the organic matter present in it, despite some species occasionally migrating to the surface in search of food. They create short, semi-permanent tunnels. Earthworms that are endogeic have some pigmentation. They don't move as quickly or have as thick of muscle layers as epigeic earthworms. Sizes of endogeic species range from 2.5 to 30 cm. While native endogeic earthworms are frequently found in tussock grasslands, introduced endogeic earthworms are frequently found in agricultural soils (Suthar, 2009).

C. Anecic

Anecic earthworms live underground, up to three meters below the soil's surface, in permanent burrows. They eat organic matter from the soil and gather food from the soil's surface. Anecic earthworms create extensive burrows that penetrate the subsoil both laterally and vertically. Their tunnels can have a diameter of up to 2 cm. Earthworms with anecic ancestry have some pigmentation. Local anecic species typically move slowly and have underdeveloped muscles. Native anecic species have little pigmentation because they spend so much time in the soil, and because they are so pale, they are frequently called milk worms. With lengths ranging from 3 cm to a very large 1.4 m, these deep burrowing species are also the longest (Suthar, 2009).

D. Treetop dwellers

Not all earthworm niches and habitats are underground. Native earthworms can occasionally be found in the crevices of tree branches, under the bark of dead trees, and in the epiphyte litter. In semi-saturated habitats, a variety of aquatic earthworms can also be found (Suthar, 2009).

E. Infiltration Capacity

Earthworms create a network of channels as they tunnel through the soil. The amount of soil increases as the soil residue decomposes. As a result, soil's ability to aerate itself and absorb water also increases. Some species dig deep, permanent burrows in the ground. These tunnels may play a significant role in soil drainage, especially during periods of heavy rainfall. The burrows also reduce erosion caused by surface water. The soil's overall porosity and drainage are increased by other species' horizontal burrowing in the top few inches of the soil (Suthar, 2009).

F. Pedogenesis and Aggregation

Biological processes in soil always have an impact on the pedogenesis and aggregation of soil. By creating new humus and tying microaggregates together with the help of their mucilaginous secretions to form organo-mineral complexes, earthworms aid in the development of stable soil aggregates (Suthar, 2009).

G. Bioindicator

The level of heavy metal toxicity, toxic pollutants, and other anthropogenic activities in the soil can be accurately detected by earthworms. Some groups of worms have the ability to bioaccumulate specific metal elements, indicating the level of contamination in the soil (Suthar, 2009).

H. Vermicomposting

Vermicomposting is nothing more than the use of earthworms to compost complicated organic material into humus. For their effectiveness in vermicomposting, earthworm species like Eudrilus eugeniae, Eisenia fetida, Lumbricus rubellus, and Perionyx excavatus are well known. Vermicomposting is a reasonably priced, non-destructive, and environmentally responsible method of turning biomass into compost that has been enriched with plant nutrients that may be of use (Suthar, 2009).

CONCLUSIONS

The presence of earthworms in the soil reveals a lot about the condition of the soil. One of the most significant detritivores, these ecosystem engineers control soil fertility and plant growth directly through their activity. They have the potential to function as bioindicators of soil health in addition to changing the physical, chemical, and biological properties of the soil.

FUTURE SCOPE

Future studies should concentrate on the co-construction of stable macroaggregates by a number of ecosystem engineers, such as plant roots and earthworms, as well as belowground feces, which may represent significant amounts of casting activities. Although neither earthworm nor plant signatures are powerful enough to overcome the background signature of bulk organic matter, this new strategy seems promising in the long run.

Conflict of Interests. None.

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