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REVIEW ARTICLE

EARTHWORM AS SOIL ECOSYSTEM ENGINEERS: A REVIEW

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Abstract

Earthworm and microorganisms are interdependent on each other. The interactions between them help to regulate the biogeochemical cycle of terrestrial life. A large diversity of fungi, bacteria, yeast, actinomycetes and protozoa are found to be present in the gut and cast of earthworms. Their number and species depend on their feed substrates obtained in soil. It has been studied that the microbial proliferation is more in the casts, due to the environment prevailing-rich nutrient supply and large surface area available for growth and reproduction of the microbes that lead to the enhanced microbial activity and humic acid contents in casts. Diversity of microorganisms is also found in vermicompost and vermiwash. This in turn depended on the raw material used for compost. A significant increase was noted in flora after composting. Within an ecological group, habitat was found to be a more important determinant of the gut wall associated community composition than the host species.

Introduction:-

Earthworms are popularly known as the "farmer's friend" or nature's plowman". Earthworm has a high influence on microbial community as well as physical and chemical properties of soil. The primary decomposers of organic matter are microorganisms. The microorganisms and earthworms act symbiotically to accelerate and enhance the decomposition of organic matter. Microbial activity in the earthworms gut, cast and soil is very essential for the breakdown and release of nutrients in available form to plants.

Vermicomposting is a suitable system for studying microbe earthworm interactions[1]. Microbial activity is stimulated by favorable conditions like moisture content, pH and high concentration of mucus in the anterior part of the gut. This microbial activity is enhanced in the midgut resulting in the digestion of soil organic matter. The digested material is partially absorbed in the posterior part of the gut and in the midgut. Epigeic species which consume considerable amounts of raw organic matter have a range of enzymatic activities, originating from ingested micro flora. For instance the presence of fungal endophytes substantially increases the nutritional value of grass leaves for *E. fetida*[20].

Soil, is the soul of infinite life that promotes diverse micro flora. Soil bacteria viz., Bacillus, Pseudomonas and Streptomyces etc., are prolific producers of secondary metabolites which act against numerous coexisting phytopathogenic fungi and human pathogenic bacteria[39]. Soil, the major reservoir of microbes, meets all the food

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requirement of earthworms and this has necessitated the establishment of different kinds of relationship between earthworms and microbes. They are:

1. Microbes form a part of food for earthworm.
2. Microbes are proliferated in the gut.
3. Earthworm help in the distribution of microbes.
4. Together with earthworm microbes mineralize and humifies organic matter[8, 29, 36].

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. 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[21]. Enhanced nutrients (N, P, K, S, Ca, Mg, Fe, Zn) in the casts of earthworm, compared to the surrounding soil, was due to mineralization taking place in the gut as well as in the casts[18, 35].

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[15, 23, 34, 42]. The composition of micro flora in the earthworm gut varies depending on the earthworm species[26]. So the microorganisms of substrates that the earthworms ingest are also equally important. The most common species found to be active are shown in the Table 1 below.

Table 1:-

Sr.	Types of Microbes	Species
1	Fungi	*Aspergillus fumigates, Aspergillus flavus, Mucor plumbeus, Rhizopus species*
2	Bacteria	*Klebsiella pneuminiae, Pseudomonas aeruginosa, Enterobacter aerogenes, Enterobacter cloacae, Morganella morganii, Bacillus subtilis*
3	Actinomycetes	*Streptomyces albus, Streptomyces somaliensis*
4	Protozoa	*Amoeba proteus, Paramecium trichium, Uglena viridis*

Earthworm and microbes together mineralize humified organic matter and facilitates chelating of some metal ions[8, 32, 37, 41]. Earthworms have the capacity to utilize soil microbes as their food[19, 38]. Growth and reproduction in earthworms require C and N and these were obtained from litter, grit and microbes[15]. 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[7, 15]. 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[2, 15, 45]. They play an important role in enhancing the nutrients in the soil by mineralization through the enzymes secreted by the microbes and earthworms[35, 38, 46]. The increase in humic acid in vermicasts, sequesters elements like Zn, Mn and Fe from their complex forms and chelate them (Ranganthan, unpublished observation), making them available for uptake by the plants. The diverse functional groups of humic acid are known to be very reactive with metal ions[2]. Thus the role of microbes-earthworms throws light on the flux of nutrients, particularly trace elements, between microbes → earthworms → 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[14]. 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[5, 22]. Earthworms influence primary soil functions and processes, such as soil structure formation, soil carbon dynamics and biogeochemical cycles[6, 30]. 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[30]. 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[4]. 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 epigeic and both *Lumbricus terrestris* and *L. friend* are anaerobic species[44].

Significance of Gut Microbiota:-

Differences in the digestion and assimilation processes in earthworms suggest the possible existence of ecological group-specific gut micro biota[31]. Although the microbial profile of the gut content of soil depends on feed resources[13, 17, 24, 25]. It is not a coincidental combination of the microorganisms present in soil[43]. The evolutionary relationship between earthworm burrowing and feeding habits and the gut microbial community has not been defined as gut-associated microbial communities[10, 27, 48]. 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[33]. 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[27].

The tenacity of earthworms for specific food types reflects their metabolic capacity[6]. Physical, physiological and biochemical properties dictate the metabolic capacity of the earthworm gut[13]. In mammals, gut morphology significantly influences bacterial community compositions[33]. 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[3, 40, 47]. 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[28] and it is likely that differences in diet among earthworm ecological groups lead to the establishment of different bacterial communities.

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 scales.

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