REVIEW OF LITERATURE

Physico-chemical properties of soil and earthworm casts:

Physico-chemical characteristics viz. temperature, moisture, \( p^H \) and nutrient contents of the soil regulate the population and activity of macro and microorganisms. Chemical and biological properties of the soil in turn are regulated by the soil organic matter, which is one of the major pool of carbon and nutrients, and also regulates to a large extent the physical properties of the soil. Interaction between plants, microbes and the physico-chemical processes in soil together with the soil organic matter dynamics influence nutrient and water availability to the plants. Nitrogen is the most limiting nutrient in many plant communities (Vitousek, et. al. 1982 and Vitousek and Howarth, 1991). Phosphorus is another essential element of all living organisms. Many workers have reported that earthworm casts are known to have more favourable physico-chemical properties for crop growth than the parent soil (Lunt and Jacobson, 1944, Lal and Akinremi, 1983; Mulongoy and Bedoret, 1989 and Krishnamoorthy, 1990).

Aldag and Graff (1975) kept the earthworms *Lumbricus terrestris* in pots and reported that the content of available nitrogen in their casts was 40% greater than in the surrounding soil.

Needham (1957) suggested that very little nitrogen is excreted in the faeces of earthworms but other workers have reported considerably more nitrogen in casts than in surrounding soil (Lunt and Jacobson, 1944 and Graff, 1971).

Barley and Jennings (1959) reported that the excretions, which include mucoproteins secreted by gland cells in the epidermis, and ammonia, urea, and possibly uric acid and
allantoin, in a fluid urine excreted from the nephridio pores, contribute a significant amount of readily assimilable nitrogen to soil. The increase in inorganic nitrogen in casts is due to these excretory products and mucus, as well as through the increased rates of mineralization of organic nitrogen by microorganisms in the casts.

Sharpley and Syers (1976) observed that the rate of release of inorganic and organic phosphorus in the earthworm casts was about four times faster than that in the surface soil during 3 days of sequential extraction.

Deka (1981) studied the seasonal variation in organic matter content, nitrogen and available phosphorus in 1 year, 10 years and 20 years fallow and noted a sharp decline in NH₄-N level in February followed by a sharp increase during March-April. Lowest level of organic matter was noted during the period from June-August followed by a subsequent period of almost uniform level of organic matter.

Fardeau (1981) showed that exchangeable and water extractable inorganic P in casts of *Pontoscolex corethrurus* was more abundant than in non-ingested control soils.

Lee (1985) reported that casts had higher quantities of carbon, phosphorus (5-10 times more) than the surrounding soil.

Shaw and Pawluk (1986a,b) reported a greater amount of clay-associated carbon in earthworm casts than in the surrounding soil.

Mulongoy and Bedoret (1989) noted higher pH values, organic carbon and total nitrogen in the casts as compared to the surrounding soil. They observed significant correlations between properties of the casts and of the corresponding soil for various chemical and biological parameters.

Tiwari, et. al. (1989) observed a seasonal variation in the concentration of inorganic
phosphorus in earthworm casts with highest levels relative to the surrounding soil occurring in the middle of July-August.

Rastin et al. (1990) investigated a number of biological and biochemical factors in different horizons from the upper and lower slopes of a spruce forest. They reported that \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) concentrations in the soil solution showed significant correlation with most of the biological and biochemical soil factors investigated.

Scheu (1991) reported that secretion of mucus in casts and from the body wall accounted for 63% of total carbon losses from a geophagous earthworm, \emph{Octolasion lacteum}.

Lavelle et al. (1992) observed that levels of inorganic N were often quite high in fresh casts.

Lopez-Hernandez et al. (1993) reported that the contents of water soluble and exchangeable phosphorus were much greater in earthworm casts than in the surrounding tropical soil.

Schrader and Zhang (1997) reported that the organic carbon content of the earthworm casts was higher than the parent soil. They also reported that the organic C content in the casts of \emph{Lumbricus terrestris} was more than that of \emph{Aporrectodea caliginosa}.

**Fungal population of the soil, the casts and the earthworm gut:**

Microorganisms constitute an important component of earthworm diet. Many reports suggested that fungal tissues are digested as the principle source of nourishment (Morgan, 1988). Several authors (Dash et al. 1986 and Striganova et al. 1989) after examinations of the contents of the alimentary tracts of earthworms and comparison with the surrounding soil have also made reports on preferential consumption of fungal species by earthworms in field studies after examinations of the contents of the alimentary tracts of earthworms and comparison with the surrounding soil.
The physico-chemical characters of the soil may regulate the microbial population and their activities (Mishra, 1966; Tiwari et. al. 1987; Waksman, 1927 and Warcup, 1950).

Waksman (1927) considered organic matter, soil pH, moisture, temperature, aeration and nature of the crop grown to be responsible for the distribution and abundance of microbe in soil.

Ghilarov (1963) reported that increase in the number of microorganisms in the earthworm gut and casts were twice than that observed in the surrounding soil.

Went (1963) reported little or no difference between microfloral population of earthworm casts and soil.

Mishra (1966) suggested that factors like organic matter, pH, moisture content, aeration, temperature, season and the state of litter decomposition governed the distribution of microbes in the soil.

Mishra and Kanaujia (1972) analysed the ecological aspects of soil fungi in relation to climatic condition, vegetation and soil physico-chemical characteristics and they found the organic matter, pH, soil depth and season played a critical role in the distribution of mycoflora.

Dash, et. al. (1979) reported that earthworm casts contained higher number of microorganisms than the surrounding soil.

Dkhar (1983) reported that maximum concentration of available phosphorus in the soil during the month of July in Jhum, Terrace and valley lands and suggested that this maybe due to the greater microbial activity and release of soluble phosphate because of suitable temperature.
Dkhar and Mishra (1987 & 1992) observed that the microbial population was higher in the soils of permanent agriculture as compared to that of ‘slash and burn’ type of shifting agriculture. They further reported that the soil of the valley land harboured maximum microbial populations followed by the terrace land agriculture and minimum in the soil of jhum land agriculture.

Tiwari et al. (1987, 1989 & 1991) reported that soil moisture significantly alters the microbial population, its activity and relationships between parameters. They reported that earthworm casts contained higher microbial population as compared to the soil of pineapple plantations and also observed positive correlation between microfungal population and organic C, available P and exchangeable K in pineapple orchard soil.

Mulongoy and Bedoret (1989) reported higher microbial counts in the casts than in the surrounding soil.

Behera et al. (1991) while conducting an ecological investigation of some microfungi in a tropical forest soil of Orissa could isolate 36 fungal species and one sterile mycelia from the soil. They observed seasonal variations of fungal population to be more pronounced in upper soil layers. They also observed positive correlation between fungal population, soil moisture and organic matter content.

Tiwari and Mishra (1993) sampled earthworm casts and adjacent soil at 30 different sites in India and observed that the casts usually contained larger fungal population and a greater number of fungal species than the surrounding soil.

Tiwari and Sharma (1998) reported that the fungal and bacterial populations in highland soils increased with increase in altitude up to 1100 m, but thereafter, the populations declined sharply. They also observed positive correlation between fungal and bacterial populations with organic matter content of the soil.
Edwards and Fletcher (1988) suggested that bacteria were of minor importance in the diet, algae of moderate importance while protozoa and fungi were the major source of nutrients. Parle (1959 & 1963a) showed that number of microorganisms increased exponentially from the anterior to the posterior portions of the earthworm gut.

Dash et al. (1979) isolated 19 species of microfungi from the soil, 16 species from the anterior portion of the earthworm's gut and 8 species from the posterior portion of the gut.

Tiwari et al. (1990) could isolate a total of 17 species of microfungi from the gut and casts, out of which 16 occurred in the anterior region, 12 in the middle region and 10 in the posterior region of the gut. They suggested that there existed a gradient with regard to the digestive capability of different regions of the gut of earthworms for utilisation of microfungi as food.

Dkhar and Mishra (1991) observed that the fungal population was maximum in the foregut and minimum towards the hindgut of the earthworm *Amynthas diffringens*.

Kristufek et al. (1992) reported that the number of fungi increased during passage through the gut of *Lumbricus rubellus*.

Moody et al. (1996) studied the fate of fungal spores associated with the wheat straw decomposition on passage through the guts of two earthworms *L. terrestris* and *Aporrectodea longa*. They found that the effect of passage through the earthworm gut on the viability of spores of saprophytic fungi was found to vary depending upon the fungal and earthworm species. They also found that *Fusarium lateritium, Agrocybe temulenta, Trichoderma* sp., *Mucor hiemalis* and *Chaetomium globosum* failed to germinate. They further reported that germination of *Trichoderma* sp. and *Mucor hiemalis* was significantly
reduced in the case of *I. terrestris* whereas the reverse was observed in the case of *A. longa* in which there was a significant increase in the spore germination after gut transit.

Ranee and Dkhar (1998) observed that the fungal population in the gut of the earthworm was of the order: hindgut > foregut > midgut. They also observed that there was a gradual decrease in the number of fungal species from soil to hindgut.

**Earthworm population:**

Many efforts have been made in recent decades to find an optimal method to determine earthworm population in soils. Generally handsorting and formalin extraction seem to be the most suitable methods for the determination of earthworm populations in the field (Nordstrom and Rundgren, 1972; Walther and Snider, 1984; Lee, 1985; Mukherji and Singh, 1986 and Dunger and Fiedler, 1989). Handsorting and subsequent washing and sieving can also improve the efficiency of separating earthworms from soil (Lavelle, 1978; Walther and Snider, 1984 and Judas, 1988).

Evans and Guild (1947c) suggested that temperature and moisture of the soil and the obligatory diapause or the period of quiescence during adverse conditions is the another important factor affecting the activity of the earthworms.

Gerard (1967) reported that in pasture soil in England, *Aporrectodea chlorotica*, *A. caliginosa* and *A. rosea* usually occurred within 10 cm of the soil surface. However, when the soil temperature fell below 5°C or when the soil became dry, individuals of these species move to deeper soil.

Edwards and Lofty (1977) suggested that earthworm population dynamics are relatively complex and that they depend principally on the availability of soil moisture and temperature for development and activity.
Lee (1985) suggested that the availability of organic matter was probably the most important factor determining the size of earthworm populations.

Reddy (1987) observed that earthworms were found in the upper (0-10 cm) layer of the soil during the rainy season but penetrated downwards into the deeper soil as winter approached.

Bhadauria and Ramakrishnan (1989) reported that earthworm population declined significantly after slashing and burning. They also suggested that population size was significantly correlated with soil moisture, temperature and organic matter.

Reddy and Pasha (1993) reported that earthworms migrated to deeper layers during winter and summer. They suggested that their seasonal population structure was significantly influenced by the seasonal patterns in rainfall, soil temperature, pH, phosphorus, organic carbon, nitrogen and potassium. They further suggested that the physical factors of the soil were collectively more effective in causing the seasonal variation in their population size than the chemical factors.

**Decomposition by earthworms:**

Earthworms play a major role in the breakdown of organic matter and the release and recycling of nutrients. They remove the partially decomposed plant litter and crop residues from the soil surface, ingest it, fragment it and transport it to the subsurface layer.

Edwards and Heath (1963) who placed disks, cut from freshly fallen oak and beech leaves in nylon bags of four different mesh sizes observed that after one year 92% of the total oak leaf material and 70% of the beech litter had been removed by earthworms. They observed that earthworms ate not only the softer parts of the leaves but also the veins and the ribs.
Anderson *et al.* (1983) measured nitrogen mineralization in forest soil incubated with oak litter and with or without the earthworm *Lumbricus rubellus*. They observed that *L. rubellus* increased the mobilization of nitrate nitrogen by 10 times and that of ammonium nitrogen by 80 times relative to soil without earthworms.

Ferriere and Bouche (1985) reported that the entire carbon content of the earthworm could turnover in 40 days and also suggested that a considerable portion of this turnover was due to mucus secretion MacKay and Kladivko (1985) reported that after 36 days, pots with no earthworms had retained 60% of the soybean residues and 85% of the maize residues, whereas, pots with earthworms had only 34% of the original soybean residues and 52% of the original maize residues.

Hendrix *et al.* (1987) estimated that earthworms were responsible for about 30% of the total heterotrophic soil respiration, during late winter and early spring, in a no-tillage agro-ecosystem in the south eastern U.S. The population densities at their site reached a maximum of nearly 1000 individuals/m².

Haimi and Huhta (1990) showed that *L. rubellus* increased the mass loss of coniferous forest humus by a factor of 1.4 in a 48 week laboratory incubation. They also observed that earthworm respiration accounted for 21-32% of the increase in CO₂ evolution. They further reported that the earthworm species *L. rubellus* and *Dendrobaena octaedra* significantly raised the pH of the leaching waters and humus and observed that both the worms increased N-mineralization but influenced the level of PO₄³⁻-P only slightly.

Haimi and Boucelham (1991) in a laboratory study reported that *L. rubellus* had a positive effect on CO₂ evolution during the period when the worms were present.

Ruz-Jerez *et al.* (1992) reported that mineral nitrogen concentrations were about 50% greater in soils with earthworms than in soils without earthworms. They also observed
that earthworms increased CO₂ evolution after the addition of clover and grass by 1.35 and 1.25 fold respectively.

Haimi and Einbork (1992) reported that the earthworm *Aporrectodea caliginosa tuberculata* had mixed the organic matter into the mineral layer of the soil. They also observed that pH values and N concentrations in the leaching water showed no consistent differences between soil with and without earthworms. They further reported that the worm increased the CO₂ production of the soil.

Scheu (1993a,b) reported that earthworms increased the mineralization of ¹⁴C-labelled lignin in limestone soils. He reported that during 253 days of laboratory incubations, *Octolasion lacteum* increased the mineralization of labelled lignin for the first 10 weeks, but decreased later.

Bohlen and Edwards (1995) reported that earthworms increased soil respiration rates during the first 15 days of incubation by 1.24 to 2.42 folds.

Schindler Wessels *et al.* reported that earthworms had significant effects on soil respiration, but their effects varied seasonally and were influenced by environmental conditions. Most of the significant effects of earthworms on soil respiration were observed during the growing season.

Wessells *et al.* (1997) reported that earthworms had significant effects on soil respiration but their effects varied seasonally and were influenced by environmental conditions.

Cortez and Bouche (1998) reported that anecic earthworms make litters more palatable by a particular type of behaviour. They reported that during the first stage of decomposition the litters were ploughed in by earthworm casts involving both an increase of microbial activity and preliminary microbial litter decomposition.
Role of earthworms in dispersal:

Earthworms can enhance the dispersal of microorganisms by ingesting them at one location from a particular food source and egesting them elsewhere or by transporting microbes that adhere to their body surface. They can spread soil fungi including pathogens, throughout the soil by dispersing spores and hyphal fragments.

Baweja (1939) suggested that earthworms dispersed the pathogenic fungus *Pythium*.

Khambata and Bhatt (1957) suggested that earthworms dispersed spores of harmful fungus *Fusarium*.

Hutchinson and Kamel (1956) inoculated sterilized soil with several species of fungi and reported that the rate of spread of the fungi through the soil was much greater when worms were present than when they were absent.

Hoffman and Purdy (1964) reported that teleospores produced by *Telletia controversa*, a pathogen causing dwarf bunt could pass through the earthworm gut without harm.

Redell and Spain (1991a) reported the spread of spores and hyphal fragments of mycorrhizal fungi in undigested root fragments in the gut of the earthworm *Pontoscolex corethrurus*.

Stephens *et. al.* (1994a,b) reported that *A. trapezoides* enhanced the rates of dispersal of *Rhizoctonia meliloti* as well as the levels of root nodulation in infected alfalfa plants. They further showed that the earthworm *A. trapezoides* dispersed the bacterium *Pseudomonas corrugata* 2140R strain through the soil thereby resulting in bacterial colonisation of the roots of wheat seedlings.
Toyota and Kimura (1994) found that the earthworm *Pheretima* sp. dispersed the soil borne plant pathogen *Fusarium oxysporum* in the topsoil but decreased the total propagules of this pathogen.

Brown (1995) suggested that by feeding, burrowing and casting activity earthworms influenced the dispersal of microorganisms throughout the soil.

**Effect of earthworms on plant growth:**

Many workers (Gavilov, 1963; Nielson, 1965; Russell, 1910; Edwards and Lofty, 1980 and Atlavinyte and Vanagas, 1982) have attempted to demonstrate the beneficial effects of earthworms on plant growth and yields of crops.

Russell, (1910) obtained increased dry matter yields of the order 25% in the presence of earthworms and attributed this to improvements in the physical condition of the soils. And reported that less evaporation occurred in pots containing earthworms, because the soil surface was covered by earthworm casts.

Gavilov (1963) processed extracts of the tissues, mucus, coelomic fluid and casts of *Lumbricus terrestris* and showed that they contained plant growth factors, probably produced by the coelamobyes.

Nielson (1965) claimed that he detected in eight species of lumbricids and two megascoleids, the production of some plant growth substances in the alimentary tract which are later voided as casts. He compared the increases in plant growth due to the earthworm extracts with those of IAA and reported a significant effect of these extracts on plant growth.

Springett and Syers (1979) compared the growth of ryegrass seedlings in the presence of casts of *A. caliginosa* and *L. rubellus* to the growth without casts, and concluded that the earthworms must alter the nutrient availability, alter the plant’s ability to
take up nutrients or affect the growth mechanisms of plants. They also concluded that L. rubellus casts probably contain an auxin-like substance, or some substances that modifies the effects of the plant’s auxins.

Edwards and Lofty, (1980) investigated the influence of the earthworms on the growth and yield of barley in field soils that had been direct-drilled for 6 years and compared the growth of barley in the plots inoculated with earthworms with plots to which no earthworms were added. They found significant differences in the yield of barley, and the growth rate of the barley was greater in plots inoculated with earthworms.

Graff and Makeschin (1980) tested the effects of substances produced by L. terrestris, A. caliginosa and E. fetida on dry matter production of ryegrass in Germany and concluded that yield-influencing substances were released into the soil by all the three species, but did not speculate on the nature of the substances.

Atlavinyte and Vanagas, (1982) demonstrated a clear strong correlation between the number of earthworms and the growth of barley. Increased yields were proportional to the number of earthworms that had been added.

Tomati et. al. (1983) tested composts produced from organic waste by the action of earthworms as media for growing ornamental plants and reported that the composts influenced the dwarfing, time of flowering, lengthening of internodes and the stimulates rooting.

Tomati et. al. (1983) tested composts produced from organic waste by the action of earthworms as media for growing cereals and mushrooms and reported that the composts influenced their growth.

James and Seastedt (1986) reported a positive effect of earthworms on root growth of big bluestem.
Edwards and Burrows (1988) described data on the growth of a wide range of plants in media produced by the processing of organic waste by \textit{E. fetida}. And speculated that the success of these media, even at high dilutions, and the growth patterns of the plants, could be explained best by postulating a hormonal effect on plant growth.

Lavelle, (1992) reported that the earthworm \textit{Pontoscolex corethrurus} increased the growth of the grain crops.

Spain \textit{et. al.} (1992) found that the growth of \textit{Panicum maximum} increased significantly after inoculation of soil in which it grew in the presence of the earthworms \textit{Chuniodrilus zielae} and \textit{Stuhlmannia porifera}.

**Decomposition:**

Plant organic material is subjected to many agents that promote decomposition, including both microorganisms and animals. Much organic matter (litter) particularly the tougher plant leaves, stems and root material, breaks down more readily after being eaten by soil inhabiting invertebrates and acted upon by enzymes in their intestines. Earthworms are probably the most important invertebrates in many soils playing a major role in the recycling of organic matter. The plant litters differ in their chemical composition depending upon the species. The chemical composition of litter changes as the process of decomposition proceeds. The soluble organic and inorganic components leach out of the material within a very short span of time which may range from a week to few months depending upon the physical structure of the material. Macromolecules such as lignin, cellulose, hemicellulose, sugar, amino acid etc. have been generally considered as a measure of degree of decomposition.

Edwards and Heath, (1963) reported that earthworms ate not only the softer parts of the leaves but also veins and ribs.
Bohlen et al. (1995b) studied the decomposition of crop residues in maize agroecosystems in which earthworm populations had been decreased, increased or left unmodified, in enclosed plots. They showed that earthworms, in particular *L. terrestris* actively selected crop residues that contain the greatest amount of nitrogen thereby increasing the loss of nitrogen from the residues to a greater extent than they increased the loss of carbon.

Parmelee et al. (1990) reported significant increases in the amount of particulate organic matter in plots with decreased earthworm populations illustrates the extremely important role of earthworms in the fragmentation and breakdown of organic matter as well as in the release of nutrients that it contains.

Daniel (1991) showed that leaf litter consumption by juvenile *L. terrestris* could be described by a non-linear function of soil temperature, soil water potential and food availability. These three factors probably govern the amounts and rates of food consumed by most litter feeding earthworm species.

Martin (1991) reported that casts of the tropical earthworm *Millsonia anomala* had much less coarse organic matter than the surrounding soil, indicating that the larger particles of organic matter were fragmented during passage through the earthworm gut.

Curry and Bryne (1992) found that the decomposition rate of straw in the presence of earthworms was increased by 26-47% compared with straw from which earthworms were excluded.

Ketterings et al. (1995) reported that earthworms can decrease the total amount of plant residues but appear to increase the C:N ratio of the remaining residues, which may have important consequences for patterns of nitrogen mineralization or immobilization by microorganisms associated with the residues.
Edwards and Bohlen (1996) reported that organic matter that passes through the earthworm gut and is egested in their casts is broken down into much finer particles so that a greater surface area of the organic matter is exposed to microbial decomposition.

Christensen (1988) reported that dead earthworm tissues contributed 20-42 kg nitrogen/ha to the soil during the autumn in three arable systems in Denmark.

Sokolov and Karpova (1965) observed that during decomposition of starch, hemicellulose and amino acids in organic residues decomposed at a faster rate while lignin was the last to decompose.

Mishra and Tiwari (1984) reported that sugars and amino acid concentration declined very fast during the initial periods of decomposition and became stabilised in the later periods.

Berg and Stoaf (1980) suggested that decomposition of litter may be divided into at least two phases. In the first phase saprophytic fungi decompose soluble substances and then non-lignified carbohydrates (cellulose and hemicellulose). In the late decomposition phase, on the other hand, primarily lignin and lignified cellulose remained.

Dkhar and Mishra (1992) reported that the amount of cellulose, hemicellulose and lignin contents of the decomposing maize litters varied with different litter types. They observed maximum amount of lignin in the root followed by the stem and minimum in the leaf. They also observed significant positive correlation between percentage weight remaining and various chemical compounds associated with different types of litter.