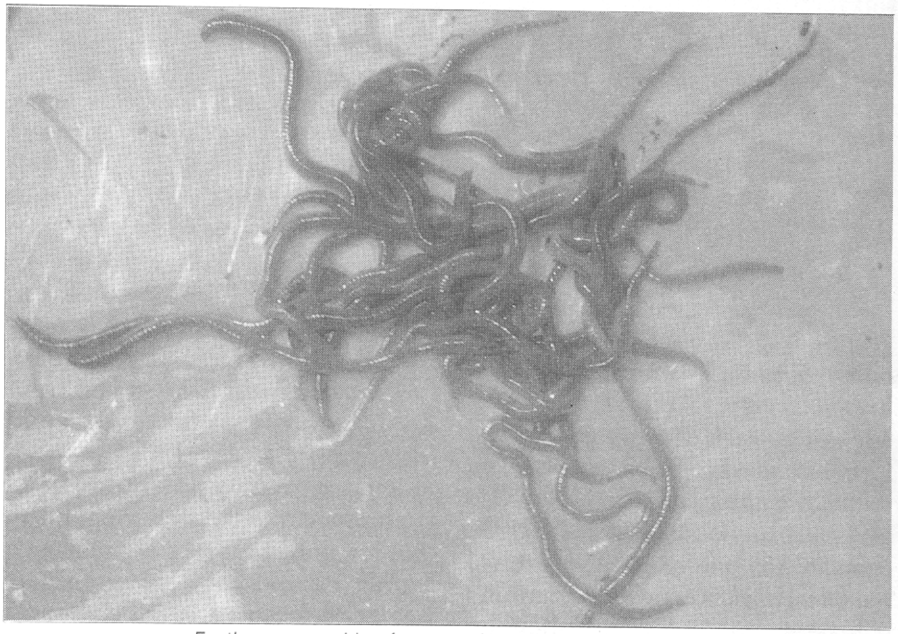
Prospects of Improving Coconut Productivity Through Vermiculture Technology

S.R.Prabhu, P.Subramanian C.C.Biddappa and B.M.Bopaiah

Central Plantation Crops Research Institute
Kasaragod 671 124, Kerala



Earthworm capable of composting coconut palm wastes

Coconut, one among the important cash crops grown in Kerala has an important role in the socio-economic development of the state. Despite the fact that Kerala has the status of primary coconut producing state, the productivity continues to be very low. Among the several reasons for this, poor soil fertility and soil characteristics that influence soil productivity should be playing a major role. Many studies in Kerala have revealed that most of coconut farmers either do not use inorganic fertilizers or apply insufficient quantities. Enhancing the use of fertilizers may not be the solution to the problem atleast on long term basis, as fertilizers are not going to be cheaper and the adverse effects of fertilizers on soil productivity are well known (Biddappa *et.al.*,1996). So, of late there is emphasis on the development of agricultural technologies which will permit sustained coconut production in low input systems. Sustaining the growth and yield of crops requires maintenance of soil structure and fertility or soil quality (Lavelle *et.al.*,1989) and soil quality is closely linked with and reflected in the activity ,diversity and abundance of soil microflora and fauna (Doran and Parkin, 1994). Thus, one of the ways to promote sustainability is by manipulating the biological processes that maintain soil fertility in natural ecosystems. The possible applications of these biological mechanisms in maintaining and improving soil quality in coconut plantations and for composting ligno-cellulosic biomass from coconut palm is discussed in this paper.

Biological Systems of Regulation (BSRs) of Soil Fertility

Soil supports the growth of innumerable and diverse communities of microflora, microfauna and macrofauna and various biological strategies adopted by soil systems through these organisms are responsible for recycling of plant nutrients (Coleman *et.al.*,1983). Most of the plant nutrient transformations including organic matter decomposition is carried out by an array of microorganisms and it is well known that these have a role in the nutrition of coconut palm (Thomas *et.al.*,1991). Hence, the management procedures aiming to promote adequate biological communities are considered to be an important field of research (Lavelle *et.al.*,1989). But, unfortunately much of these microbes are largely dormant, in resting stages with low metabolic rates, awaiting suitable conditions (Lavelle, 1997). These inactive forms are reawakened by specific organic substrates produced by roots and macrofauna, such as earthworms. This priming effect is supposed to play an important role in soil function (Lavelle and Gilot, 1994). Rhizosphere and drilosphere, the area of influence of roots and earthworms respectively, in soil are the main biological systems of regulation (BSRs), where most of the active microbiological activities are regulated. The soil degradation that follows mismanagement is always linked to destruction or loss of biological systems of regulation. Conversely, soil fauna and root activities are always intense in situations where soil fertility has been restored or maintained on a sustainable basis. Hence it is clear that restoration or rehabilitation techniques that do not adequately address biological regulation by soil fauna and roots are doomed to failure (Lavelle *et.al.*, 1993).

Soil fauna play a crucial role in biological turn over and nutrient release by fragmenting plant residues, resulting in enhanced microbial activity (Anderson *et.al.*, 1983). As earthworms constitute the highest biomass among the tropical soil macrofauna (Fragoso and Lavelle, 1992) and have been indicated as potential indicators of sustainability of agro-ecosystems (Christenson, 1991), the following discussion would be centred around them.

Earthworms : the Most Useful Animal to the Mankind

Earthworms are soft bodied soil-dwelling animals belonging to class Oligochaeta of the phylum Annelida. Within the different taxonomic groups of soil organisms, earthworms play an important role in degradation of soil organic matter and maintaining and improving soil structure (Edwards and Lofty,1977) and the changes in physical, chemical and biological properties brought about by them can modify plant growth (Lee,1985). The Greek philosopher Aristotle in the 4th BC had rightly termed them "the intestine of the earth".

The structure of earthworm community is mainly determined by temperature (Lavelle,1983) and tropical countries harbour more species. India has more than 400 species

Following the classification of Lavelle (1981), five functional groups of earthworms were distinguished, i.e., *epigeics* , that are fully pigmented and live in and feed on leaf litter, *anecics*, that have an antereo-dorsal pigmentation and live in burrows that they dig into soil, but feed on a mixture of soil and leaf litter that they collect at night from the soil surface and *endogeics* ,that are not pigmented and live in the soil, feeding on soil taken from the A1 horizon without any selection (*mesohumic endogeics*), or with a selection towards organic particles (*polyhumic endogeics*) or soil from deep (20-40 cm) horizons (*oligohumic endogeics*). But such a demarcation could not be made with respect to earthworms in the tropics and majority of them are *endogeics* and only a few are litter feeders (Dash,1978, Kale and Krishnamoorthy,1978).

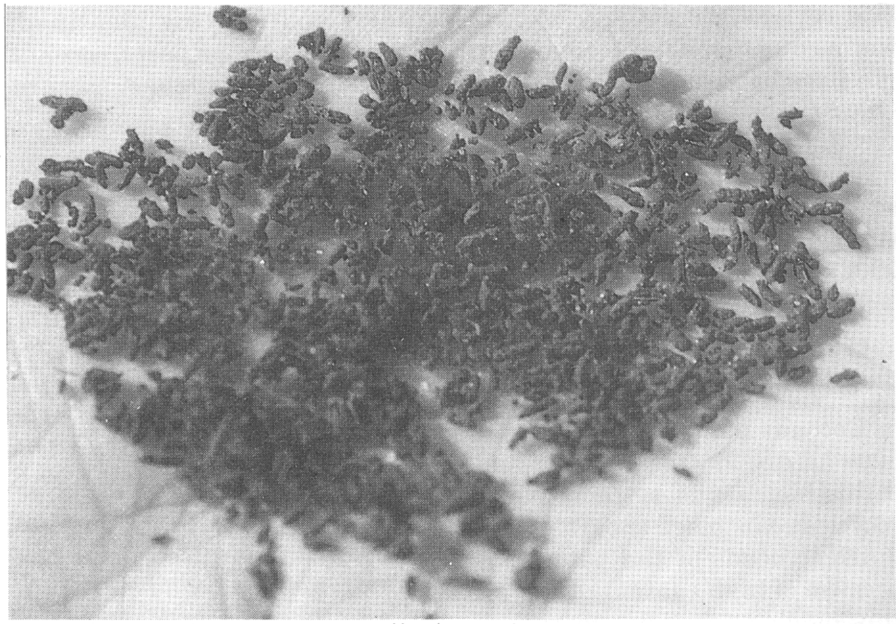
According to Wallwork (1983),earthworms may participate in soil forming process by their influence on soil pH,as agents of physical decomposition, by promoting humus formation, by improving soil structure and by enriching soil.

All groups of earthworms have definite role to play in soil systems. *Epigeics* act as effective agents of comminution and fragmentation of leaf litter that they transform into stabilized organic matter. One kilogram of these worms can decompose 4 to 5 kilograms of organic waste per day. *Anecics* modify the soil physical properties by their burrowing activity and enhance the decomposition of plant debris by burrowing and mixing them into soil (Lavelle,1988).*Endogeics* feed on soil organic matter that they digest in association with soil microbes (Lavelle,*et.al.*,1995). They may ingest annually several hundreds to 1200 tonnes of dry soil per hectare per year (Lavelle,1984) and a portion of it is deposited as fertile top soil. Stork and Eggleton (1992) termed these soil dwellers as "ecosystem engineers" because of their ability to profoundly affect the soil structure and hence major soil processes through the structures they build. Their burrowing, feeding and casting activities lead to enhanced soil aggregate stability, better water infiltration and reduced soil erosion .This ,over a long periods of time leads to a specific pedological process called "zoological ripening of soils" (Bal,1982). Long term incubation studies of casts and control soils indicated that mineralization of carbon from casts may reduce due to the physical protection of organic matter in stable soil aggregates (Martin,1991) and this may be an important mechanism of organic matter stabilization in tropical soils where abiotic factors favour rapid mineralization (Lavelle and Martin,1992).There is also considerable evidence for earthworm effects on humus formation (Brussaard and Juma, 1996)

Many studies have demonstrated the potential of introduction of geophagous earthworms to enhance the productivity of soils which lack them (Stockdill,1982). Butt *et.al.* (1997) standardized a method known as earthworm inoculation unit (EIU) technique for introducing deep burrowing worms. This consists of a polybag culture of earthworms in a mixture of soil and feed. As these units contain all the growth stages of earthworm, they establish well in soil, after introducing the units in a pit.

Earthworms are of potential importance in the nutrient dynamics in cultivated soils. Stephens *et.al.* (1994) showed that foliar concentration of a wide range of elements was elevated in the presence of earthworms, suggesting that the mechanism by which earthworms increase plant growth was in part through increasing the availability and uptake of nutrients from soils. Estimates of worm contribution to nitrogen turn over ranged from 3 to 63 kg N/ha/year (Anderson,1983; Parmelee and Crosseley, 1988). Atlavinyte and Vanagas(1973) reported a higher phosphorous content in earthworm casts than surrounding soil. Satchell (1983) linked the phosphatase activity in the gut of earthworms to lability of bound phosphorous in soils. An expanded root system in the presence of earthworms (Edwards and Lofty, 1980) allows plants' access to water and nutrients deep in soil (Lee,1985).

Many plant growth promoting substances secreted by earthworms have been found to be responsible for the lush growth of plants observed after applying vermicastings. Many biologically active substances such as auxins, cytokinins and vitamin B12 have been identified in earthworm worked soils (Atlavinyte and Daciulyte, 1969; Krishnamoorthy and Vajranabhaiah,1986; Tomati *et.al.*1988). The plant growth promoting effects of leachates from vermicomposting beds (vermiwash) might be due to these biochemicals.



Vermi compost

Earthworms for Composting of Plant Residues

Decomposition is a key process in maintaining soil fertility through its two contrasting subprocesses, the mineralization and humification (Lavelle,*et.al.*1993). Rarely have the activities of macroorganisms as grazers been included in studies of the nutrient cycling process or separated from the activities of soil microfauna (Coleman *et.al.*,1983). Evidence is now accumulating to the effect that faunal grazers may be responsible for a significant fraction of mineralization previously attributed to microflora (Elliot *et.al.*,1984, Lee,1985).

The decomposition of plant residues includes three processes: comminution (physical breakdown by animals and enzymes), catabolism (action of animal and microbial enzymes) and leaching of water soluble materials. Soil fauna participate in decomposition process by comminution and catabolism (Swift *et.al.*,1979). Earthworm feeding increases the surface area exposed to microbial attack, resulting in fast disappearance of plant litter. The degradation product of organic wastes obtained by earthworm consumption is known as vermicompost and is mostly composed of vermicastings , which are loosely packed granular aggregates of semi-digested organic matter.

The surface - dwelling epigeic earthworms alone can remain active all through the year and can very well be maintained under semi-natural conditions. They being surface - active worms, the released excrements can be easily collected to use as organic manure (Kale,1992). A number of species of epigeics are now available for commercial production of vermicompost. Various species differ considerably in their growth and reproductive rates, size and in their environmental requirements. *Eudrilus eugeniae* and *Eisenia foetida* are commonly used for waste degradation. Kale *et.al.* (1982) suggested the possible role of *Perionyx excavatus* for vermicompost production. But under prevailing conditions of South India, *Eudrilus eugeniae* (African night crawler) serves as the most suitable species (Kale and Bano,1988).

There is possibility of ameliorating impoverished soils lacking top soil by the application of vermicompost ,wherever introduction of worms is not possible. As vermicastings are aggregates of semi-digested organic matter, it meets the energy needs of various beneficial microbes for establishment and serves as a comfortable niche. When this manure is added, it forms the needed top soil and also revives the activity of local worms due to the improvement in physico-chemical status of soils. Once these local worms are revived, they improve soil aeration by their burrowing activity and soil turn over, thus rejuvenating the impoverished soils (Kale, 1992).

Vermicomposting of Lignocellulosic Biomass from Coconut Palm

Coconut palm produces about 8000 kg dry matter /ha/year and if this biomass is systematically recycled, can meet a part of the nutrient needs of the palm. But because of high content of lignin, this biomass decompose rather slowly. Though soil fauna do not prefer plant litter rich in lignins, their role is greater in decomposition of such low quality biomass (Tian *et.al.*1997).Couture and Fortain (1983) considered soil macrofauna as regulating agents of lignolysis. Scheu (1992) suggested that soil macroorganisms may affect lignin degradation indirectly by litter comminution, fungal spore dispersal, litter-soil mixing, and grazing. Earthworm activity is also known to increase lignin degrading microbes and lignin degradation (Kale*et.al.*,1991, Scheu,1993). Vinceslas-Akpa and Loquet (1997) found more lignilysis in vermicompost compared to that in ordinary compost.

So, we examined the possibility of employing epigeic earthworms for reducing the composting period and for the production of vermicompost. A number of local earthworm types from coconut plantation were collected and maintained. They were tested for their survival in coconut palm usufructs ,multiplication rate, and composting efficiency. Among these, one of the strains capable of efficiently composting the biomass was selected for further studies and is being identified. Among the various parts, coconut leaflets gave the highest outturn of vermicompost.

The waste materials from coconut plantation was consumed by earthworms only after they have undergone preliminary decomposition. The spent substrates obtained after cultivation of oyster mushrooms (Thomas *et.al.*,1997) were also consumed by the earthworms very fast compared to fresh materials.

A low cost technology for large scale vermicompost production has been standardised using the coconut biomass weathered in rains for three to four months. The biomass can be used as such without chopping, thus saving a lot of labour .The commercial production of vermicompost was tested in a cement tank (7.5x2x1m) using the large, pigmented and active local earthworm strain. The vermicomposting bed was watered and mulched regularly and protected from direct sun light. One ton of coconut palm usufructs and 100 kg of cowdung was converted into pure granular vermicastings by 3.5 kg of worms after 60 days, leaving behind only midrib of the leaves. The recovery of vermicompost was about 70 per cent , but depended on the type of materials and extent of degraded base materials used. The vermicompost had a C:N ratio of 9.9, N 1.8 per cent, P 0.21 per cent and K 0.16 per cent.

The possibility of vermicomposting of coconut palm biomass was also tested inside a coconut plantation in littoral sandy soils. For this, a trench (5x1x1 m) was dug in the interspace of four coconut palms and the procedure was repeated as above. The conversion of organic materials into vermicompost was completed in 90 days and the recovery was about 70 per cent. It is clear that by vermicomposting, it is possible to substitute the entire nitrogen requirement and considerable amount of potash and phosphorus. The recycling of organic materials through vermicompo-sting has more relevance in sandy soils poor in organic carbon and this technology may have practical applications

Low potash content of the compost might be due to the leaching of potash from the base materials in rain water. Efforts are on to enhance the nutrient content of the compost by mixing other plant materials with coconut palm biomass for vermicomposting.

Our studies have also revealed that fresh coir pith can also be composted using the local earthworm. For this, coir pith has to be mixed with 30 per cent by weight of cow dung and in about 100 days the earthworms complete the composting process, leaving behind coconut fibres. The C:N ratio of compost obtained was 22. Nitrogen content was 1 per cent, with phosphorus content being 0.47 per cent and potassium 0.7 per cent. Efforts are on to reduce the time of composting and increase the efficiency, using various local earthworms. Ramesh and Gunathilagaraj (1996) had also reported the degradation of coir pith using *Perionyx excavatus*.

Prospects of Enhancing Earthworm Activity in Coconut Plantations by *in situ* Recycling of Biomass in Basins

Valuable plant nutrients are removed from coconut gardens by off-site disposal and use. Recycling of wastes *in situ* would return these nutrients to soil and make them available for plant growth. *In situ* recycling mimics natural forest condition. Initially it results in increased worm activity on the site, thereby expanding its capacity to recycle litter (Cothrel *et.al.*,1997). Mulching and recycling *in situ* would provide coconut farmers with a simple, inexpensive and ecologically sound method of coconut leaf disposal. Soil surface mulch management can result in increased earthworm activity (Lee,1985) by lowering the soil temperature and better retension of moisture. Tian *et.al.* (1993) have emphasized the role of low quality mulches in sustaining crop production due to their greater effects on soil microclimate. As coconut palm usufructs also degrade slowly, they may have better influence on the activity of earthworms. Surface mulching with rotten coconut leaves in the basins has been found to be the best method to conserve moisture and increase coconut yield (Joseph *et.al.,* 1994). In the preliminary trials, we observed a build up of local earthworm population when *in situ* recycling of coconut leaves was done in the basins, confirming the beneficial effects of mulching on the ability to restore the biological systems of regulation. About 5.6 million tonnes of coconut leaves are available in Kerala per year (Pillai and Rohtagi,1981) As the use of leaves for thatching and as fuel has reduced, there is good scope for *in situ* recycling of the leaves by vermiculture technology.

Conclusion and Future Line of Work

In the recent past there has been a lot of interest in earthworms and their use for recycling of organic wastes. But not much information is available on the applications of vermiculture in coconut cultivation.Based on the information available for other crops, there is ample scope to improve the fertility of coconut plantation soils through earthworms

In future, efforts should be made to screen more strains of local earthworms for the purpose of vermicomposting and lignin degradation. The possibility of reducing the composting period and enhancing the nutrient content of the compost may have to be examined by mixing other organic wastes with coconut palm wastes. More information is needed on the field response in coconut to vermicompost application. It is known that earthworms can increase the number of nitrogen fixing bacteria and other beneficial microbes and reduce the population of nematodes and soil - borne plant pathogens (Bhat*et.al.*,1960; Brown,1995; Mba,1997)). But, such beneficial effects of earthworms in coconut plantation soils is not known and demand more studies. The adverse effects of chemicals used regularly in coconut plantation on the activities of earthworms has to be studied in detail.

References

Anderson, N.C. (1983) Nitrogen turn over by earthworms in arable plots treated with farm yard manure and slurry. In :*Earthworm Ecology*. (Ed.), J.E.Satchell. Chapman & Hall, London.pp.139-150.

Anderson,J.M., Ineson,P. and Huish,S.A. (1983) Nitrogen and cation mobilization by soil fauna feeding on leaf litter and soil organic matter from deciduous woodlands. *Soil Biol. Biochem.*: 15:463-467.

Atlavinyte,O., and Daciulyte, J. (1969) The effect of earthworms on the accumulation of vitamin B12 in soil. *Pedobiologia* 9 :165-170.

Atlavinyte,O., and Vanagas,J. (1982) The effects of earthworms on the quality of barley and rye grain. *Pedobiologia* 23 : 256-262.

Bal, L. (1982) Zoological ripening of soils. Centre for agricultural publications and documents, Wageningen, The Netherlands.

Barois, I. and Lavelle, P. (1986). Changes in respiration rate and some physico-chemical properties of a tropical soil during transit through *Pontoscolex corethrurus* (Glossosscolecidae, Oligochaeta). *Soil Biol. Biochem.* 18: 539 - 541.

Bhat, J.V., Khambata,S.R., Maya,G.B., Sastry,C.A., Iyer,R.V. and V.Iyer (1960) Effect of earthworms on the microflora of the soil. *Indian J.Agrl.Sci.*30:106-114.

Biddappa, C.C., Upadhyay, A. K., Hegde, M. R. and Palaniswami, C. (1996) Organic matter recycling in plantation crops. *J.Plantation Crops* 24:71-85.

Brown,G.G. (1995) How do earthworms affect microfloral and faunal community diversity. *Plant Soil* 170 : 209-231.

Brussaard,L. and N.G.Juma (1996) Organisms and humus in soils. ***In:*** Humic substances in terrestrial ecosystems (Ed. Piccolo, A), Elsevier Science B.V, Oxford.

Butt, K.R., Frederickson, J., and Morris, R.M (1997) The earthworm inoculation unit technique : an integrated system for cultivation and soil-inoculation of earthworms. *Soil Biol.Biochem.* 29:251-257.

Christensen,O. (1991) Lumbri-cid earthworms as bioindicators relative to soil factors in different agroecosystems. ***In:*** Advances in management and conservation of soil fauna (Veeresh,G.K., Rajagopal, D., and Viraktamath, C.A (Eds.) Oxford & IBH Pub.Co., New Delhi, pp.839-849.

Coleman,D.C.,Reid,C.P.P. and Cole,C.V. (1983) Biological strategies of nutrient cycling in soil systems. *Adv. Ecol. Res.* 13:1-55.

Cothrel,S.R., Vimmerstedt,J.P. and Kost,D.A.(1997) In Situ recycling of urban deciduous litter. *Soil Biol.Biochem.* 29:295-298.

Couture,M. and Fortin,J.A. (1983) Role de la pedofaune au sein du processus de degradation de la matiere ligneuse dans deux humus forestiers. *Rev.Ecol.Biol.Sol.* 20:207-220.

Dash,M.C. (1978) Role of earthworms in the decomposer system. ***In:*** Glimpses of Ecology (Singh,J.S. and Gopal,B. Eds.) India International Scientific Publication. pp.399-406

Doran, J.W. and Parkin, T.B. (1994) Defining and assessing soil quality. ***In:*** Doran J.W., Bezdicek, D.F. and Coleman, D.C. (eds) Defining soil quality for sustainable agriculture. SSSA special publication, Wisconsin, USA.

Edwards,C.A and Lofty,J.R. (1980) Effects of earthworm inoculation upon the root growth of direct drilled cereals. *J.Appl.Ecol.*17:533-543.

Edwards,C.A. and Lofty,J.R. (1977) Biology of earthworms. Chapman & Hall, London,323 p.

Elliot,E.T.,Coleman,D.C.,Ingham,R.E. and Trofymow,J.A. (1984) Terrestrial ecosystems.. ***In:*** Proc.3rd.Int.Symp.Microb.Ecol.(Kug,M.J. and Reddy,C.A Eds.) American Society of Microbiology ,Michigan, pp.424-433.

Fragoso,C. And Lavelle,P. (1992) Earthworm communities of tropical rain forest. *Soil Biol.Biochem.*24:1397-1408

Joseph,P.A.,Nambiar,I.P.S.,Rajagopalan,A., Nair,R.R. and Nair,N.K.(1994) Surface mulching of rotten coconut leaves is beneficial to coconut trees in laterite soils. *Indian Coconut J.* 25:(8) :2-4

Kale, R.D. (1992) Earthworms : nature's quiet and the biggest gift. *Spice India* (Sept.) : 2-9.

Kale, R.D. and Bano,K. (1988) Earthworm cultivation and culturing techniques for the production of Vee Comp.83 E UAS *Mysore J.Agric.Sci.*2 :339-344

Kale, R.D., Bano,K. and Krishnamoorthy, R.V. (1982) Potential of *Perionyx excavatus* for utilizing organic wastes. *Pedobiologia* 23 :419-425.

Kale,R.D. and Krishnamoorthy,R.V. (1978) Distribution and abundance of earthworms in Bangalore. *Proc. Indian. Acad. Sci.* 87B:23-25

Kale,R.D., Bano,K., Sreenivasa, M.N., Vinayak,K. and Bagyaraj, D.J. (1991) Incidence of cellulolytic and lignolytic organisms in the earthworm worked soils. ***In:*** Advances in management and conservation of soil fauna (Veeresh,G.K., Rajagopal,D. and Viraktamath,C.A. Eds.) Oxford & IBH, New Delhi, pp.599-603

Krishnamoorthy,R.V. and Vajranabhaiah, S.N. (1986) Biological activity of earthworm casts : an assessment of plant growth promoter levels in the casts. *Proc.Indian Acad.Sci.(Anim.Sci.)*95:341-351.

Lavelle, P. (1981) Strategies de reproduction chez les vers de terre. *Acta Oecol* 2 : 117 - 133.

Lavelle, P. (1984) The soil system in the humid tropics. Biol. Int. 9 : 2-15.

Lavelle, P. (1997) Faunal activities and soil processes : adaptive strategies that determine eco-system function. *Adv. Ecol. Res.* 27 : 93 - 132.

Lavelle, P., Lattaud, C., Trigo, D. And Barois, I. (1995) Mutualism and biodiversities in soils. *Plant Soil* 170 : 23 - 33.

Lavelle,P. (1983) The structure of earthworm communities. ***In:*** Earthworm ecology: from Darwin to vermiculture (Satchell,J.E. Ed.) Chapman and Hall,UK, pp. 449 - 465.

Lavelle,P. (1988) Earthworm activities and the soil system. *Biol.Fert.Soil.*6 :237-251

Lavelle,P. and Gilot,C. (1994) Priming effects of macroorganisms on microflora : a key process of soil function ?. *In* : Beyond the biomass (Ritz,K., Dighton,R.J., and Giller,K.E. Eds) Wiley Sayce, UK, pp.173-180

Lavelle,P.,Barois,I.,Martin,A.,Zaidi,A.,and Shaefer,R.(1989) Management of earthworm population in agroecosystems: a possible way to maintain soil fertility ? ***In:*** Ecology of arable land (Clarholm,M. and Bergstrom Eds.) Kluwer, Dordrecht, pp.109-122

Lavelle,P.,Blanchart,E., Martin,A. and Martin,S. (1993) A hierarchical model for decomposition in terrestrial ecosystems : applications to soils of the humid tropics. *Biotropica* 25:13-150.

Lavelle,P.and Martin,A.(1992) Small scale and large scale effects of endogeic earthworms on soil organic matter dynamics in soils of the humid tropics. *Soil Biol.Biochem.* 24:1491-1498

Lee,K.E.(1985) Earthworms : their ecology and relationships with soils and land use.Academic press,London,411 p

Martin,A. (1991) Short-term and long-term effect of the endogeic earthworm *Millsonia anomala* (Omodeo) (Megascolecidae, Oligochaeta) of a tropical savanna,on soil organic matter . *Biol.Fert.Soil* 11 :234-238

Mba,C.C. (1997) Rock phosphate solubilizing *Streptosporangium* isolates from casts of tropical earthworms. *Soil Biol. Biochem.* 29:381-385

Parmelee,R.W. and Crossley,D.A. (1988) Earthworm production and role in the nitrogen cycle of a no-tillage agroecosystem on the Georgia piedmont. *Pedobiologia* 32 : 353-361

Pillai,C.K.S., and Rohtagi,P.K. (1981) Mechanism of deterioration of thatch and its prevention. *J.Sci. Ind.Res.*40:389-390.

Ramesh,P.T. and Gunathilagaraj, K.(1996) Degradation of coir waste and tapioca peel by earthworms. *Madras Agrl.J.*83 (1)26-28

Satchell,J.E. (1983) Earthworm microbiology. ***In:*** Earthworm ecology. (Satchell,J.E. Ed.) Chapman &Hall, UK., pp.351-364

Scheu,S. (1992) Degradation of lignin in soil microcompartments : a methodological study with three different 14C - labelled lignin substrates. *Biol. Fert.Soil* 13:160-164

Scheu,S.(1993) Litter microflora - soil macrofauna interactions in lignin decomposition : a laboratory experiment with C14 - labelled lignin. *Soil Biol.Biochem.*25:1703-1711

Stephens,P.M.,Devoren,C.W.,Ryder,M.H., and Doube,B.M. (1994) Enhanced growth of take-all affected plants associated with *Pseudomonas corrugata* 2140R and the earthworm *Aporrectodea trapezoides*(Lumbricidae).***In:*** Improving plant productivity with rhizosphere bacteria.(Ryder,M.H.,Stephens,P.M.,and Bowen,G.D. Eds.) CSIRO,Australia, pp.57-58

Stockdill, S.M.J. (1982) Effects of introduced earthworms on the productivity of New Zealand pastures. Pedobiologia 24 : 29 - 35.

Stork,N.E., and Eggleton,P. (1992) Invertebrates as determinants and indicators of soil quality.*American J.Altern.Agric.*7:38-47

Swift,M.J.,Heal.O.W. and J.M. Anderson (1979) Decomposition in terrestrial ecosystems Blackwell Scientific Publications,UK

Thomas,G.V.,Prabhu,S.R.,Reeny,M.Z., and Bopaiah, B.M.(1997) Evaluation of lignocellulosic biomass from coconut palm as substrate for cultivation of *Pleurotus sajor caju* (FR.)Singer.Poster paper presented at the Indian mushroom conference1997 held at the NRC for mushrooms,Solan. September11-12,1997

Thomas,G.V.,Rohini Iyer and Bopaiah, B.M. (1991) Beneficial microbes in the nutrition of coconut. *J.Plantation Crops* 19:127-138

Tian,G.,Kang,B.T.,and Brussaard,L. (1993) Mulching effects of plant residues with chemically contrasting compositions on maize growth and nutrient accumulation.*Plant Soil* 153:179-187

Tian,T., Kang,B.T., and Brussaard,L. (1997) Effect of mulch quality on earthworm activity and nutrient supply in the humid tropics. *Soil Biol. Biochem.* 29:369-373.

Tomati,U.,Grapelli,A., and Galli,E. (1988) The hormone-like effects of earthworm casts on plant growth. *Biol. Fert.Soil* 5:288-294

Vinceslas-Akpa,M.,and M.Loquet (1997) Organic matter transformations in lignocellulosic waste products composted (*Eisenia foetida*) : chemical analysis and 13 C CPMAS NMR spectroscopy. *Soil Biol. Biochem.*29:751-758

Wallwork,J.A.(1976) Earthworm biology. The institute of biology's studies in biology no-161. Edward Arnold, London