# ROLE OF TROPICAL EARTHWORMS IN THE DECOMPOSITION OF LEAF AND LITTER OF *Azadirachta indica*, *Eucalyptus globulus* and *Pisonia alba*

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Earthworms are a group of segmented bristle-bearing worms (Beddard, 1912) that belong to the Order Oligochaeta, Class Chaetopoda, Phylum Annelida. These organisms which form a major component of the soil biota, have been silently ploughing the land for millions of years and have also been assisting in the recycling of organic nutrients for the efficient growth of plants (Darwin, 1881).

Earthworms are found in all but the driest and coldest land areas of the world (Lee, 1985), their population contributing to 80% of the total biomass of the soil ecosystem (Watanabe, 1975; Dash, 1978; Senapati; 1980). Their role in the turning over of the soil drew the attention of the Greek philosopher Aristotle (cf. Shipley, 1970) who called the earthworms "the intestines of the earth".

Gilbert White (1770) wrote "earthworms though in appearance a small and despicable link in the chain of nature, yet, if lost, would make a lamentable chasm.... Worms seem to be the great promoters of vegetation, which would proceed, but lamely without them...." (cf. Edwards and Lofty, 1972).

Darwin (1881) observed that earthworms prepare the ground in an excellent manner for the growth of fibrous-rooted plants and for seedlings of all kinds. He described the role of earthworms in the breakdown of dead plant and animal material in the soil and forest litter, and in the maintenance of soil structure, aeration and fertility. His findings that earthworms play a beneficial role in soil formation and soil fertility have since been acknowledged by Hensen (1877), Müller (1884), Urquhart (1887), Lee and Foster (1991), Alban and Berry (1994) and Nooren *et al.*, (1995).

Earthworms are one among the most ancient of the terrestrial animal groups known to have originated during the pre-Cambrian, some 650-570 million years ago (Glaessner *et al.*, 1969). Most of these earthworms are inhabitants of soil, including litter layers and above ground habitats such as animal dung, rubbish heap, rotting logs, under the bark of standing trees and in organic material accumulated at the bases of epiphytes (Lee, 1985). Their distribution is generally determined by edaphic factors such as temperature, moisture, pH, aeration and texture of soil, and organic matter (Murchie, 1958; Kaleemurrahman and Ismail, 1981).

The distribution of organic matter in soil greatly influences earthworm distribution. The choice of an environment rich in organic matter by earthworms has often been reported (Satchell, 1955, 1980; Murchie, 1958; Barley, 1959 a,b;

Edwards *et al.*, 1970; Kale and Krishnamoorthy, 1978, 1981; Mishra, 1980; Abbott and Parker, 1980; Ismail, 1983, 1986, 1993, 1994 a, b, c, 1995 a, b; Ismail *et al.*; 1990, 1993). Soils that are poor in organic matter do not usually support a large number of earthworms and conversely fewer the earthworms, thicker is the mat of decaying organic matter on the soil surface. (Richardson, 1938; Raw, 1962; Stockdill, 1966; Potter *et al.*; 1990; Clements *et al.*, 1991).

Earthworms are saprophagous forms being either detritivores or geophages (Lee, 1985). The detritivores feed either on plant litter or on other plant debris in the organic matter rich surface - soil horizons. The geophagous forms ingest large quantities of organically rich soil. Based on ecological strategies Bouché (1971, 1977) recognised 3 categories of worms namely, the epigeics which are predominantly phytophagous; the anecics which are geophytophagous and the endogeics which are geophagous.

Earthworms play a key role in the removal of plant litter, dung and other organic material from the soil surface (Edwards and Lofty, 1977). The role of earthworms in the decomposition process of litter in several ecosystems has been well documented (Richardson, 1938; Raw, 1962; Madge, 1966; Hoogerkamp *et al.*

1983; Ismail, 1983; Satchell, 1983; Senapati and Dash, 1984; Kapur and Kapil, 1986; Tian *et al.*, 1995).

Rapid removal of plant litter from the soil surface in a variety of habitats by lumbricid earthworms has been reported by several authors including Waters (1951), Heath and King (1964), Nielson and Hole (1964), Perel and Sokolov (1964), Heungens (1969), Maldague (1970), Zajonc (1971), Malone and Reichle (1973), Vimmerstedt and Finney (1973), and Piearce (1983).

Earthworms can consume large amounts of litter and the amount they ingest seems to depend more on the total amount of suitable organic matter available than on other factors (Edwards and Bohlen, 1996). The consumption of leaf litter of different plant species has been estimated for several species of earthworms (Franz and Leitenberger, 1948; Needham, 1957; Raw, 1962; van Rhee, 1963; Satchell, 1967; Lavelle, 1978; Sugi and Tanaka, 1978; Curry and Bolger, 1984; Knollenberg *et al.*, 1985; Haimi and Huhta, 1990; Daniel, 1991; Kaushal *et al.*, 1994).

Earthworms have been shown to selectively consume different types of plant materials (Darwin, 1881; Tembe and Dubash, 1961; Brown *et al.*, 1963; Edwards and Heath, 1963; Satchell and Lowe, 1967; Wright, 1972; Kale and Krishnamoorthy, 1981; Piearce, 1989). The rate of litter break down depends upon the type of litter apart

from other edaphic factors (Swift *et al.*, 1979; Tripathi and Singh, 1992; Kittle *et al.*, 1995). The content of water soluble polyphenols in the litter are reported to be inversely proportional to the rate at which the litter is consumed (Satchell, 1967; King and Heath, 1967). Litter becomes more palatable to earthworms after a few weeks of weathering (Edwards and Lofty, 1977; Zicsi, 1983). Litter rich in protein is reported to be more readily acceptable by earthworms (Wittich, 1953).

Rutigliano *et al.*, (1996) reported that the rate of decomposition of the litter of *Fagus sylvatica* and needles of *Abies alba* is influenced by lignin, the lower the concentration of lignin, higher being the rate of decomposition.

The importance of soil invertebrates in the break down of leaf litter has been well documented by using techniques of confining either intact litter or leaf discs in nylon mesh bags of different mesh sizes and burying them in soil or litter (Edwards and Heath, 1963; Witkamp and Crossley, 1966; Curry, 1969; Arianoutsou, 1993; Takeda, 1995; Verhoeven and Toth, 1995). Litter bag exclusion experiments have indicated that fragmentation and decomposition of plant material is tremendously enhanced when worms are allowed to enter the bag (Edwards and Heath, 1963; Heath *et al.*; 1966; Perel *et al.*, 1966; Hendriksen, 1990; Curry and Byrne, 1992; Wise and Schaefer, 1994).

Experiments with neem litter have revealed the annual loss to be 50% and 58% in coarse and fine mesh bags respectively (Reddy, 1992). Decomposition of leaf litter of albizia (*Pariaserianthes falcataria*), eucalyptus (*Eucalyptus tereticornis*) and teak (*Tectona grandis*) using mesh bags have indicated the decomposition of eucalyptus litter to be the slowest (Sankaran, 1993). The decomposition rate of acacia litter was reported to be faster than *Eucalyptus tereticornis* in Karnataka (Swamy, 1989) and Kerala (Sankaran, 1993) while that of the latter is reported to be slower than that of poplar (*Populus deltoides*) (Chander *et al.*, 1995). Woods and Raison (1983) have reported that the weight losses of abscissed leaves in one year ranged from 25% for *E. pauciflora* to 39% for *E. delegatensis*. The k value (annual decomposition rate constant) however is reported to be lower in *E. tereticornis* litter compared to *E. camaldulensis* in Dehradun, India (Sharma and Pande, 1989; Bahuguna *et al.*, 1990).

The role of earthworms *viz., Lampito mauritii, Polypheretima elongata, Pontoscolex corethrurus* and *Perionyx excavatus* in litter breakdown in the tropics has been discussed (Senapati and Dash, 1984; Krishnamoorthy, 1986; Kale and Bano, 1988; Ismail, 1993, 1994 a,b,c; 1995 a,b; 1996). Studies have indicated that *P. excavatus* disintegrated the litter more rapidly than other species and even performed well in the breakdown of eucalyptus as compared to the other species (Krishnamoorthy, 1986).

Intensive studies on litter dynamics have been carried out in many parts of the world especially in temperate zones (Anderson and Swift, 1983) but only limited data on these aspects are available from the tropics. There is also a great paucity of detailed information about the part played by tropical earthworms in litter breakdown.

## PRESENT INVESTIGATION:

Neem (*Azadirachta indica*), an important tree of the Indian sub-continent; *Eucalyptus globulus*, an aromatic lofty evergreen tree and *Pisonia alba*, a small ornamental evergreen tree, are of considerable interest in India because of their medicinal properties.

The present research investigates the role of the tropical earthworms *Perionyx excavatus* and *Lampito mauritii* in the break down of the leaves and litter of *A. indica*, *E. globulus* and *P. alba*.

The rates of breakdown of fresh leaves and fallen litter of *A. indica*, *E. globulus* and *P. alba* have been assessed on exposure to various fractions of the soil fauna using mesh bags of three mesh sizes, coarse ($4mm^2$), medium ($1.5mm^2$) and fine ($0.75mm^2$).

The changes in the polyphenolic and tannin content of the leaves and litter of *A.indica, E.globulus* and *P. alba* have been monitored during the course of the decomposition process.

Carbohydrate and protein contents and calorific values of the leaves and litter of *A. indica, E. globulus* and *P. alba* have been determined to assess their impact on preference for palatability.

Litter bag experiments have been conducted both under laboratory and field conditions to ascertain relative differences in leaf and litter decomposition.

Earthworm numbers and their biomass have been estimated in these different experiments before and after their completion.

It is evident from the experiments conducted both in the laboratory and field that leaf discs prepared from fresh leaves of *A. indica, E. globulus* and *P. alba* were disintegrated faster than those of their corresponding litter. This is likely to be due to the higher moisture content and carbohydrate and protein content of fresh leaves than their litter.

Decomposition of leaf discs and litter discs was fastest in the coarse mesh bags which provided access to earthworms, and slowest in the fine mesh bags which barred entry of earthworms.

A progressive increase in the rate of decomposition of the leaf and litter discs in mesh bags is correlated to the decrease in polyphenolic and tannin contents, with weathering.

Data have been subjected to statistical analysis and are discussed in the light of previous reports.

# REFERENCES


Abbott, I. and Parker, C.A., 1980. The occurrence of earthworms in the wheat belt of Western Australia in relation to the land use and rainfall. *Aust. J. Soil Res.*, 18 : 343-352.

Alban, D.H. and Berry, E.C., 1994. Effects of earthworm invasion on morphology, carbon and nitrogen of a forest soil. *Applied Soil Ecology* 1 : 243-249.

Anderson, J.M., and Swift, M.J., 1983. Decomposition in tropical forest. *Tropical Rain Forest: Ecology and Management.* In: S.L. Sutton, T.C. Whitmore and A.C. Chadwick (eds.) Blackwell, Oxford, pp. 287-309.

Arianoutsou, M., 1993. Leaf litter decomposition and nutrient release in a maquis (ever green sclerophyllous) ecosystem of North-Eastern Greece. *Pedobiologia*, 37:65-71.

Bahuguna, V.K., Negi, J.D.S., Joshi, S.R. and Naithani, K.C., 1990. Leaf litter decomposition and nutrient release in *Shorea robusta* and *Eucalyptus camaldulensis* plantations. *Indian For.*, 116 : 103-114.

Barley, K.P., 1959a. The influence of earthworms on soil fertility. II. Consumption of soil and organic matter by the earthworm *Allolobophora caliginosa*. *Aust. J. Agr. Res.*, 10 : 149- 158.

Barley, K.P., 1959b. Earthworms and Soil fertility. IV. The influence of earthworms on the physical properties of a red brown earth. *Aust. J. Agric. Res.*, 10 : 371-376.

Beddard, F.E., 1912. *Earthworm and their allies.* Cambridge University Press, London, 150pp.

Bouché, M.B., 1971. Relations entre les structures spatiales et fonctionelles des écosystèmes, illustrées par le rôle pédobiologique des vers de terre, In *La Vie dans les sols, Aspects Nouveaux, Etudes Experimentales* (P.Pesson ed.) Gauthier- Villars, Paris, pp. 187-209.

Bouché, M.B., 1977. Stratégies lombriciennes. In *Soil organisms as components of ecosystems.* [U. Lohm and T. Persson eds], *Ecol. Bull.* (Stockholm), 25 : 122-132.

Brown, B.R., Love, C.W. and Handley, W.R.C., 1963. Protein-fixing constituents of plants. *Rep. For Res. London*, Part III, 90-93.

Chander, K., Goyal, S. and Kapoor, K.K., 1995. Microbial biomass dynamics during the decomposition of leaf litter of poplar and eucalyptus in a sandy loam. *Biol. Fertil. Soils*, 19 : 357-361.

Clements, R.O., Murray, P.J. and Sturdy, R.G., 1991. The impact of twenty years absence of earthworms and three levels of nitrogen fertilizer on a grassland soil environment. *Agric. Ecosyst. Environ.*, 36, 75-86.

Curry, J.P., 1969. The decomposition of organic matter in soil. I. The role of the fauna in decaying grassland herbage. *Soil. Biol. Biochem.*, 1 : 253-258.

Curry, J.P. and Bolger, T., 1984. Growth, reproduction and litter and soil consumption by *Lumbricus terrestris L.* in reclaimed peat. *Soil Biol. Biochem.*, 16, 253-257.

Curry, J.P. and Byrne, D., 1992. The role of earthworms in straw decomposition and nitrogen turnover in arable land in Ireland. *Soil Biol. Biochem.*, 24, 1409-1412.

Daniel, O., 1991. Leaf litter consumption and assimilation by juveniles of *Lumbricus terrestris L.* (Oligochaeta, Lumbricidae) under different environmental conditions. *Biol. Fertil. Soils*, 12, 202-208.

Darwin, C., 1881. *The Formation of vegetable mould through the action of worms, with observation on their habitats.* Murray, London, 298pp.

Dash, M.C., 1978. The role of earthworms in the decomposer system. In: *Glimpses of Ecology* (J. Singh and B. Gopal eds.) International Scientific Publications; Jaipur, pp. 399-406.

Edwards, C.A. and Bohlen, P.J., 1996. *Biology and Ecology of Earthworms.* 3rd edn. Chapman and Hall, London, 426pp.

Edwards, C.A. and Heath, G.W., 1963. The role of soil animals in the breakdown of leaf material. *In: Soil Organisms*, (J. Doeksen and van der Drift eds.) North Holland Publishing Co. Amsterdam. pp. 76-80.

Edwards, C.A. and Lofty, J.R., 1972. *Biology of earthworms*. Chapman and Hall Ltd., London, 283pp.

Edwards, C.A. and Lofty, J.R., 1977. *Biology of earthworms* 2nd edn., Chapman and Hall, London, 333pp.

Edwards, C.A., Reichle, D.E. and Crossley, D.A. Jr., 1970. The role of soil invertebrates in turnover of organic matter and nutrients. In *Ecological Studies, Analysis and Synthesis*. Springer-Verlag, Berlin. pp.147-172.

Franz, H. and Leitenberger, L., 1948, Biological-Chemical investigations into the formation of humus through soil animals. *Ost. Zool. Z.*, I, 498-518.

Glaessner, M.F., Priess, W.V. and Watter, H.R., 1969. Pre- Cambrian Columnar Stromotolites in Australia: Morphological and Stratigraphic analysis. *Science*, 164 : 1056-1058.

Haimi, J. and Huhta, V., 1990. Effects of earthworms on decomposition processes in raw humus forest soil: a microcosm study. *Biol. Fertil. Soils*, 10, 178-183.

Heath, G.W. and King, H.G.C., 1964. The palatability of litter to soil fauna. *Proc. VIII Int. Congr. Soil Sci. Bucharest*, pp.979-986.

Heath, G.W., Arnold, M.K. and Edwards, C.A., 1966. Studies in leaf litter break down. I. Breakdown rates among leaves of different species. *Pedobiologia*, 6: 1-12.

Hendriksen, N.B., 1990. Leaf litter selection by detritivore and geophagous earthworms. *Biol. Fertil. Soils*, 10, 17-21.

Hensen, V., 1877. Die Thätigkeit des Regenwarms (*Lumbricus terrestris*) fur die Fruchtbarkeit des Erdbodens. Z. *Wiss. Zool.*, 28, 354-364.

Heungens, A., 1969. The physical decomposition of pine litter by earthworms. *Pl. Soil,* 31 : 22-30.

Hoogerkamp, M., Rogaar, H. and Eijsackers, H.J.P., 1983. Effect of earthworms on recently reclaimed polder soils in the Netherlands. In: *Earthworm Ecology* (J.E. Satchell, ed.). Chapman and Hall, London. pp. 85-105.

Ismail, S.A., 1983. Taxonomical and bioecological studies on some earthworms from Madras. *Ph.D., Thesis, Madras University.* 85pp.

Ismail, S.A., 1986. Earthworm resources of Madras. *Proc. Nat. Sem. Org. Waste Utiliz. Vercomp. Part B: Verms and Vermicomposting.* (M.C. Dash, B.K. Senapati and P.C. Mishra eds.) Sambalpur University, Orissa, India. pp: 8-15.

Ismail, S.A., 1993. Applied Biology of Earthworms. *Keynote Papers and Extended Abstracts. Congress on traditional sciences and technologies of India, I.I.T., Bombay,* pp: 10.27-10.30.

Ismail, S.A., 1994a. Vermitech: The use of local species of earthworms in agriculture. *Changing Villages,* 13: 27-31.

Ismail, S.A., 1994b. Vermitech: Harnessing the earthworm for the benefit of mankind. *Wake up India,* 17: 18-20.

Ismail, S.A., 1994c Vermiculture in India. *Organic Matters,* 17: 23-28.

Ismail, S.A., 1995a. Vermitech for natural farming. *Kisan World,* 22 : 27-28.

Ismail, S.A., 1995b. Earthworms in soil fertility management. In *Organic Agriculture* (P.K. Thampan, ed.,) Peekay Tree Crops Development Foundation, Cochin, India, pp. 77-100.

Ismail, S.A., 1996. *Vermicology : Biology of earthworms.* Orient Longman, India (In press).

Ismail, S.A., Ramakrishnan, C. and Anzar, M.M., 1990. Density and Diversity in relation to the distribution of earthworms in Madras. *Proc. Indian Acad. Sci. (Anim Sci)*, 99 : 73-78.

Ismail, S.A., Seshadri, C.V., Jeeji Bai, N. and Suryakumar, C.R., 1993. Composting through earthworms. *Monograph Series Volume 35.* Shri AMM Murugappa Chettiar Research Centre. Madras. 38pp.

Kale, R.D. and Bano, K., 1988. Earthworm Cultivation and culturing techniques for production of Vee COMP 83E UAS, Vee MEAL 83P UAS. *Mysore J. Agric. Sci.*, 22: 339-349.

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

Kale, R.D. and Krishnamoorthy, R.V., 1981. Litter preference in the earthworm *Lampito mauritii. Proc. Indian Acad. Sci. (Anim. Sci.)*, 90 : 125-128.

Kaleemurrahman, M. and Ismail, S.A., 1981. Earthworm : An Index of the physical nature of the soil. In *Progress in Soil Biology and Ecology in India* (Veeresh, G.K., ed.). University of Agricultural Sciences, Bangalore. pp : 60-63.

Kapur, M.J. and Kapil, R.P., 1986. The litter preferences and the decomposition activity of *Metaphire posthuma.* In *Proc. Nat. Sem. Org. Waste Utiliz. Vermicomp. Part B: Verms and Vermicomposting.* (M.C. Dash, B.K. Senapati and P.C. Mishra eds.) Sambalpur University Orissa. 69-74.

Kaushal, B.R., Bisht, S.B.S. and Kalia, S., 1994. Effect of diet on cast production by the megascolecid earthworm *Amynthas alexandri* in laboratory culture. *Biol. Fertil. Soils*, 17, 14-17.

King, H.G.C. and Heath, G.W., 1967. The chemical analysis of small samples of leaf material and the relationship between the disappearance and composition of leaves. *Pedobiologia*, 7, 192-197.

Kittle, D.L., McGraw, J.B. and Garbutt, L., 1995. Plant litter decomposition in wet lands receiving acid mine drainage. *Jour. of Environ Qual.*, 24 : 301-306.

Knollenberg, R.W., Merritt, R.W. and Lawson, D.L., 1985. Consumption of leaf litter by *Lumbricus terrestris* (Oligochaeta) in a Michigan woodland flood plain. *Am. Midl. Nat.*, 113, 1-6.

Krishnamoorthy, R.V., 1986. Role of some tropical earthworms in nutrient cycling. In *Proc. Nat. Sem. Org. Waste Utiliz. Vermicomp. Part B: Verms and vermicomposting* (M.C. Dash, B.K. Senapati and P.C. Mishra eds.) Sambalpur University Orissa. 47-65.

Lavelle, P., 1978. Les vers de terre de la savanne de Lamto (Côte d'Ivoire). Peuplements, Populations et fonctions de l'écosystème. *Publ. Lab. Zool. E.N.S.*, 12, 1-301.

Lee, K.E., 1985. *Earthworms : Their ecology and relationships with soils and land use.* Academic Press, Sydney, Australia, 411pp.

Lee, K. and Foster, R.C., 1991. Soil fauna and soil structure. *Aust. J. Soil Res.*, 29, 745-776.

Madge, D.S., 1966. How leaf litter disappears. *New Scientist*, 32, 113-115.

Maldague, M.E., 1970. Rôle des animaux édaphiques dans la fertilité des sols forestiers. *Publ. Inst. Nat. Etude. Agron. Congo. Ser. Sci.* No. 112.

Malone, C.R. and Reichle, D.E., 1973. Chemical manipulation of soil biota in a fescue meadow. *Soil. Biol. Biochem.*, 5, 629-639.

Mishra, P.C., 1980. Ecophysiological studies on tropical earthworms [Density, biomass, feeding, biology, metabolism, digestive enzymes and their role in soil]. *International Symposium on Tropical Rural Ecosystems* (Nov. 1980) Technical contributions at a glance. pp : 17-19.

Müller, P.E., 1884. Studier over Skovjord. 11. Om Muld og Mor i Egeskove og paa Heder. *Tiddskr Skvbrug*, 7: 1-232.

Murchie, W.R., 1958. Biology of the Oligochaete *Eisenia rosea* (Savigny) in an upland forest soil of Southern Michigan. *Am. Midl. Nat.*, 66 : 113-131.

Needham, A.E., 1957. Components of nitrogenous excreta in the earthworm *Lumbricus terrestris L* and *Eisenia foetida Savigny*. J. *Exp. Biol.*, 34 : 425-446.

Nielson, G.E. and Hole, F.E., 1964. Earthworms and the development of coprogenous A, horizons in forest soils of Wisconsin. *Soil Sci. Soc. Am. Proc.* 28, 426-430.

Nooren, C.A.M., van Breemen, N., Stoorvogel, J.J. and Jongmans, A.G., 1995. The role of earthworms in the formation of sandy surface soils in a tropical forest in Ivory coast. *Geoderma*, 65 : 135-148.

Perel, T.S., Karpachevski, L.V. and Yegorova, S.V., 1966. Experiments for studying the effect of earthworms on the litter horizons of forest soils. *Pedobiologia*, 6 : 269-270.

Perel, T.S. and Sokolov, D.F., 1964. A quantitative assessment of the role of earthworms *Lumbricus terrestris* (Lumbricidae, Oligochaeta) in processing forest litter. *Zool. Zh.* 43, 1618- 1624.

Piearce, T.G., 1983. Decomposition. In *Ecological Processes*. (J.B. Whittaker and W.J. Davies eds.); Univ. of Lancaster 2 : 111-126.

Piearce, T.G., 1989. Acceptability of pteridophyte litters to *Lumbricus terrestris* and *Oniscus asellus* and implications for the nature of ancient soils. *Pedobiologia*, 33, 91-100.

Potter, D.A., Powell, A.J. and Smith, M.S., 1990. Degradation of turf grass thatch by earthworms (Oligochaeta : Lumbricidae) and other soil invertebrates. *J. Econ. Ent.*, 83, 205-11.

Raw, F., 1962. Studies of earthworm populations in orchards. I. Leaf burial in apple orchards. *Ann. Appl. Biol.*, 50: 389-404.

Reddy, M.V., 1992. Effects of microarthropod abundance and abiotic variables on mass loss and concentration of nutrients during decomposition of *Azadirachta indica* leaf litter. *Tropical Ecology*, 33: 89-69.

Rhee, J.A. van., 1963. Earthworm activities and the breakdown of organic matter in agricultural soils. In: *Soil Organisms*, (J. Doeksen and J. vander Drift eds), North Holland, Amsterdam, pp. 55-59.

Richardson, H.C., 1938. The nitrogen cycle in grassland soils with special reference to Rothamsted Park Grass Experiment. *J. agric. Sci.*, 28: 73-121.

Rutigliano, R.A., De Santo, A.V., Berg, B., Alfani, A. and Fioretto, A., 1996. Lignin decomposition in decaying leaves of *Fagus sylvatica* L and needles of *Abies alba* Mill *Soil Biol. Biochem.*, 28 : 101-106.

Sankaran, K.V., 1993. Decomposition of leaf litter of albizia (*Paraserianthes falcataria*), eucalypt (*Eucalyptus tereticornis*) and teak (*Tectona grandis*) in Kerala, India. *For. Ecol. Manage.* 56: 225-242.

Satchell, J.E., 1955. Some aspects of earthworm ecology. In: *Soil Zoology* (Kevan, D.K. Mc.E., ed) Butterworths, London. pp: 180-201.

Satchell, J.E., 1967. Lumbricidae. In *Soil Biology* (A. Burges and F. Raw eds.), Academic Press, London and New York, pp. 259-322.

Satchell, J.E., 1980. Earthworm populations of experimental birch plots on a *Calluna* podzol. *Soil Biol. Biochem.*, 12 : 311-316.

Satchell, J.E., 1983. Earthworm ecology in forest soil. In: *Earthworm ecology from Darwin to vermiculture.* (J.E. Satchell ed.) Chapman and Hall, London, New York. pp. 161-170.

Satchell, J.E. and Lowe, D.G., 1967. Selection of leaf litter by *Lumbricus terrestris.* In *Progress in Soil Biology.* (O. Graff and J.E. Satchell eds.), North Holland Publ. Co., Amsterdam, pp. 102-119.

Senapati, B.K., 1980. Aspects of ecophysiological studies on tropical earthworms (Distribution, population dynamics, production, energetics and their role in the decomposition process), *Ph.D., thesis, Sambalpur University, Orissa.* 151pp.

Senapati, B.K. and Dash, M.C., 1984. Functional role of earthworms in the decomposer subsystem. *Trop. Ecol.* 25: 52-71.

Sharma, S.C. and Pande, P.D., 1989. Patterns of litter nutrient concentration in some plantation ecosystems. *For Ecol. Manage.*, 29 : 157-163.

Shipley, A.E., 1970. *The Cambridge Natural History.* Vol.II. (S.F. Harmer and A.E. Shipley, eds) Codicote. England.

Stockdill, S.M.J., 1966. The effect of earthworms on pastures. *Proc. N.Z. Ecol. Soc.* 13, 68-74.

Sugi, Y. and Tanaka, M., 1978. Number and biomass of earthworm populations. In : *Biological Production in a Warm-temperate Evergreen Oak Forest of Japan,* (T. Kira, Y. Ono and T. Hosokawa eds.), J.I.P.B. Synthesis no.18, Univ. of Tokyo Press, pp. 171-178.

Swamy, R.H., 1989. *Study of organic productivity, nutrient cycling and small watershed hydrology in natural forests and in monoculture plantations in Chikmagalur District, Karnataka.* J.C.B.M. College, Karnataka. Final report submitted to Govt. of India. 261pp.

Swift, M.J., Heal, O.W. and Anderson, J.M., 1979. *Decomposition in terrestrial ecosystems. Studies in Ecology* 5. Blackwell Scientific Publications, Oxford.

Takeda, H., 1995. A five year study of litter decomposition processes in *Chamaecyparis obtusa* Enil. Forest. *Ecol. Res.* 10: 95-104.

Tembe, V.B. and Dubash, P.J., 1961. The earthworms : A review. *J. Bombay Nat. Hist. Soc.*, 58, 171-201.

Tian, G., Brusaard, L. and Kang, B.T., 1995. Break down of plant residues with contrasting chemical compositions under humid tropical conditions. Effects of earthworms and millipedes. *Soil Biol. Biochem.*, 27 : 277-280.

Tripathi, S.K. and Singh, K.P., 1992. Abiotic and litter quality control during the decomposition of different plant parts in dry tropical bamboo savanna in India. *Pedobiologia*, 36, 241-256.

Urquhart, A.T., 1887. On the work of earthworms in New Zealand. *Trans N Z Inst.*, 19: 119-123.

Verhoeven, J.T.A. and Toth, E., 1995. Decomposition of *Carex* and *Sphagnum* litter in Fens: Effect of litter quality and inhibition by living tissue homogenates. *Soil Biol. Biochem.*, 27 : 271- 275.

Vimmerstedt , J.P. and Finney, J.H., 1973. Impact of earthworm introduction on litter burial and nutrient distribution in Ohio Strip-mine Spoil banks. *Proc. Soil Sci. Soc. Am.*, 37, 388-391.

Watanabe, H., 1975. On the amount of cast production by the megascolecid earthworm, *Pheretima hupeiensis. Pedobiologia,* 15: 20-28.

Waters, R.A.S., 1951. Earthworms and the fertility of pasture. *Proc. N.Z. Grassl. Ass.*, pp. 168-175.

Wise, D.H. and Schaefer, M., 1994. Decomposition of leaf litter in a mull beech forest: comparision between canopy and herbaceous species. *Pedobiologia*, 38 : 269-288.

Witkamp, M. and Crossley, D.A., 1966. The role of microarthropods and microflora in break down of white oak litter. *Pedobiologia*, 6 : 293-303.

Wittich, W., 1953. Untersuchungen über den verlauf der streuzersetzung auf einem Boden mit Regenwurmtatigkeit. *Schrift Reige Forst. Fak. Univ. Gottingen*, 9, 7-33.

Woods, P.V. and Raison, R.L., 1983. Decomposition of litter in sub-alpine forests of *Eucalyptus delegatensis, E. pauciflora* and *E. dives. Aust. J. Ecol.* 8, 287-299.

Wright, M.A., 1972. Factors governing ingestion by the earthworm *Lumbricus terrestris* with special reference to apple leaves. *Ann. Appl. Biol.*, 70, 175-188.

Zajonc, I., 1971. Synusia analysis of earthworm (Lumbricidae Oligochaeta) in the Oak-horn beam forest in South-west Slovakia. In *Productivity of Forest Ecosystems* (P. Duvigneaud ed.), U.N.E.S.C.O., Paris, pp. 443-452.

Zicsi, A., 1983. Earthworm ecology in deciduous forest in Central and South East Europe. In : *Earthworm ecology : From Darwin to vermiculture.* (J.E. Satchell ed.) Chapman and Hall, London, New York. pp. 171-178.