# Conservation and sustainable management of below ground biodiversity: A review on the role of Earthworms in Indian Ecosystems

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**Abstract:** This review discusses research developments on the role earthworms, dominant soil macro fauna in many Indian ecosystems from the point of view of their(i)Community structure,biomass,and population turnover in different land uses;(ii)their bioturbation activity;(iii)interaction with soil micro flora and fauna;(iv)role in land reclamation; and (v)their utilization in vermitechnology.The review deals with the current knowledge on them and brings out the areas of future research for conservation and management of below ground biodiversity.

**KEYWORDS**: Soil fauna, Earthworms, Land uses, Vermitechnology.

**Introduction** : A number of scientists in Europe(Hansen,1877,Muller,1978,Darwin,1881,Unquhart,1887) by their observations believed that Earthworms played a beneficial role in soil formation and aided in soil fertility. Aristotole called them the ! Earth entrails! (Or intestines), probably because they lived in and moved inside the soil, churning it up (Kevan 1985). Darwin (1838, 1881)! s work drew attention to the role of earthworms in the breakdown of forest litter and in maintenance of soil structure,aeration and feretility. His book ! The formation of Vegetable Mould through the Action of Worms with Observations on their Habits ! Showed the importance of earthworms in burial of surface lying organic matter and opened a new line of research in Soil Biology. From the time of Aristotle to Darwin, not much information on the role of earthworms was available. Even after the publication of Darwins book, many believed that these animals are only the pest of crops(Feller et al.2000,2003).However some beneficial uses of earthworms such as fish bait,medicinal value,food for some native American Indians were recognized..Thus the importance of earthworms in soil fertility was not considered until the publication by Darwin, although Gilbert White (1789), Hansen (1877), Muller (1978) observed the importance of earthworms in soil in the formation of humus and worm-casts.

Darwin described how earthworms through their feeding activities and mixing of organic materials and soil minerals produce “Vegetable mould “. Until 1950(Kuhnelt, 1950), not much work was done on soil faunal activities. Satchell (1967,1983) highlighted many experimental studies especially on earthworms in European forests and their contribution to nitrogen excretion, mucous production, and biomass turnover. Later, pot experiments with different cultivated plants using earthworms in Europe showed their role in plant productivity (Edwards and Lofty, 1977, Lavelle, 1988).

Comprehensive taxonomic and distributional survey of Oligochaetes, particularly of earthworms was done by Stepheson (1923), published under the” Fauna of British India “ series .This work became obsolete due to nomenclatural changes and discovery of new taxonomic characters.The recent publication of Julka(1988) fills the much needed gap in taxonomic and distributional studies. He has reviewed the publications of Gates (1937) and other publications on Indian earthworms.In view of this Julka! s publication is taken as the most recent and scientifically acceptable publication on the taxonomy of Indian earthworms.

Some biological studies on Indian earthworms (Dutt,1948, Joshi and Kelkar,1952,Nijahwan and Kanwar,1952,Khambata and Bhatt,1957,Bhatt et al.,1960) dealt with their role in soil aggregation, effect on soil fertility and their association with microflora. Earthworms were considered as pests in tobacco nursery (Patel and Patel, Patel, 1960) and he used soapnut to control them. Bahl (1945,1947) studied their body structure,development and physiology of nephridial excretion and Saroja( 1959) worked on their respiratory metabolism.

No comprehensive ecological studies on earthworms was done in India to understand their life cycle pattern, ecology dealing with population biology and their functional role in Indian grasslands, crop fields and forest ecosystems until the studies of Dash et.al (1974),Dash and Patra,(1977,1979), Dash (1978),Kale and Krishnamoorthy(1978,1981),,Senapati and Dash(1979), Dash and Senapati(1980),Senapati and Dash(1984)and Mishra and Dash(1984) .Their studies dealt with life cycle patterns and earthworm community structure in grasslands, crop fields and forest ecosystems, functional role with regard to worm-cast production, nitrogen excretion, secondary productivity and energetics in pastures, laboratory experiments(Dash,et al.1984,1986) on interaction with microflora and soil nematodes ( Dash et al.1979,1980, 1986), earthworm as feed material for poultry, edible mushroom production (Das and Dash,1989,, Dash and Das,1989,1990 ), evaluation of some Indian earthworms for vermicomposting ( Dash and Senapati,1982,1985, Kale et al.,1982, Dash et al,1984,1985,1986).
These studies were influenced by the philosophy of International Biological Programme (IBP) although the projects were not funded by IBP.

The recent trends on the studies of earthworms are centered on their role in nutrient cycling, waste land reclamation, crop productivity, distribution of earthworms on land uses, and species invasions, vermicomposting ( Kale and Krishnamoorthy,1981, Sahu et al.,1988,Reddy and Reddy,1987,1990,1993,Sahu and Senapati,1991,Bhadauria and Ramakrishnan, 1989, 1991,1997,Bhadauria et al.,2000,Singh,1991,1997, Dash,1994,1999,Senapati,1993,Ismail,1990,1997,Lavelle et al.,`1996, Choudhuri and Bhattacharjee,2002,Chaudhuri et al.,2003,Bhattachajee and Chaudhuri,2002,Manna et al,1997,Gajalaxmi et al.,2001, Sinha et al.,2003,Tripathi and Bhardwaj,2004,Kale and Dinesh,2005),Maikhuri et al,2005, 2008).These studies have accumulated wealth of knowledge on earthworm population biology and activities in soil in different world sites resulting the current view that earthworms are the most important soil macrofauna in Indian terrestrial ecosystems and land uses. Many of the above cited laboratory studies dealing with vermicomposting are based *on Eudrilus eugeniae, Eisenia fetida (*= foetida) which are not endemic species to India.

**The purpose of writing this review is to know the status of (i) Earthworm community structure, their biomass and population turnover in different land-uses in India, (ii) to review their bioturbation activity with regard to leaf and organic matter burial, cast production (iii) to review their interaction with microflora and soil fauna, (iv) to assess their role in land reclamation,(v) to review their role in vermitechnology, specially as feed material, composting of waste organic matter by endemic species and the future prospects.**

**Earthworm Resource of India:**

**Table** 1 provides information on earthworm resources of India, particularly in Himalayan, Indo-Gangetic and Deccan peninsula (Julka, 1988). The Deccan peninsula is rich in earthworm fauna and harbours many epigeic and anecic species such as *Dichogaster bolaui, Drawida willsi, Perionyx exacavatus, Perionys* *sansibaicus, Ramiella sp., Lampito mauritii* and other species, which have potentiality for use in vermitechnology (Dash and Senapati, 1985, Dash, 1999). The North-East and Himalayan regions are also rich in many endemic and some exotic species of earthworms (Bhadauria and Ramakrishnan, 1989, 1991, Bhadauria et al 2000, Sinha et al., 2003). The exotic species *are Octolasion tyrtaeum, O. beatrix, Amynthas corticis*, *Bimostus parvus* and the endemic species are *Octochaetona beatrix, Eutyphoeus festivus, E.nanianus, E.waltoni and some Drawida species*. Distinct taxonomic groups of earthworms have evolved on every continent except Antarctica. But through human transport, many exotic species have been imported from many other regions, especially from Europe, Africa and America and some groups have been distributed world wide (Jamieson,1978,Reynolds and Cook1976,). Nine families with 53 genera with more than 400 species have been described from India (Julka,1988). The family Octochaetidae with 26 genera are more commonly found in Indian ecosystems. Besides the Deccan peninsula, and Himalayan regions, the Indogangetic plain is also rich with earthworm fauna, especially the endemic species of *Eutyphoeus in alluvial soils. In laterite and red soils of the Western Ghats the species of* Hoplochaetella *are common. The Peninsular plateaus houses many peregrine species. Pontoscolex corethrurus, an endogeic species is widely distributed in India. Besides Pontoscolex corethrus, Parryodrilus lavelee, endogeic species is common in Nilgiri Biosphere reserve in Kerala.* The similarity indices of earthworm species occurrence between different land-uses in Karnataka, India indicate that the species composition of natural forests is closer to that of coffee plantations, *Acacia* and cardamom plantations and paddy fields. Grasslands showed least similarity with other land-uses. However *Pontoscolex corethrurus*, an endogeic species was found in all land-uses (Kale et al. 2008, Chandrashekara et al.2008). Earlier studies by Dash and Patra(1977), Senapati and Dash(1981), Mishra and Dash(1984) ,Senapati (1993) showed that in pastures and mixed wood forest soils in Orissa, the earthworm species composition were not similar although *Lampito mauritii* was found in all sites (pastures, croplands, and forest sites).Studies in mid altitudes and in village land scape in Himalayan regions ( Kaushal and Bisht ,1994 , Bhadauria et al. 2000,Sinha et al.,2003 ) showed that three species in pasture soils and seven to eight species in other land uses occurred. *Amynthas sp.* is common in these sites. Biological invasion was also observed in climax forest due to the presence of exotic species. **However, much information on earthworm distribution and community structure in central and western part of India is not available**.

**Populations density, biomass and turnover**

The populations' density, biomass and turn over ( annual secondary production to average biomass) information of earthworms in many Indian sites are given in **Table-2**. The peak density in grasslands including pastures and crop lands reach about 14 million per ha. The density is comparable in pastures and crop fields and forest soils. However the density of earthworms in different land-uses in Nilgiri Biosphere reserve in Kerala is less in comparison to other sites in India. Two to eight species of earthworms have so far been recorded in any particular site. The density of earthworms in different sites depends upon soil tem perature, moisture, pH, litter and organic carbon, root biomass content, elevation etc. Highest population density has been found in pastures-grasslands during monsoon period. In NandaDevi Biosphere earthworms occurred in higher numbers in low elevation land uses, especially in agriculture land uses during monsoon and in oak forests during post-monsoon period. In higher elevation earthworms were not found in alpine pasture and *Cedrus* forests but found in agricultural land uses. Earthworms were found in Home gardens and Medicinal plantation areas in monsoon and post-monsoon period irrespective of elevation (Maikhuri et al., 2005, 2008). They also observed higher density of worms in rain fed agriculture land than irrigated land. In NilgirBiosphere, Kerala, 14 species of earthworms were recorded in different land uses. The earthworm community consisted epigeic, anecic and endogeic species. Two endogeic species, *Parryodrilus lavelee* and *Pontoscolex corethrurus* were found in most of the land uses

(Chandrashekara et al., 2008).The authors suggest that the two endogeic species because of their wide tolerance will be suitable for land restoration purpose. The maximum density of earthworms was found in coconut with perennials and mixed deciduous forest and minimum in degraded forest and coconut without perennials plantations .The density varied from 2 to 294 per m2.
The data on the amount of biomass corresponding to the population density is not available from all study sites. However the average biomass value varies from about 252 kg to 780 kg per ha with an annual turn-over varying from about one to five. The biomass data however, are comparable to many world sites (Dash, 1999).

Earthworm cocoon morphology, shape, size, colour, weight and emergence pattern and seasonal dynamics of cocoons and juveniles in tropical pasture soils in Orissa ( Senapati and Dash, 1979, Dash and Senapati,1980) and recent report of occurrence of cocoons in study sites in Karnatak,India (Kale et al. 2008) indicate that in most of the species cocoon production occurs in later period of monsoon and post monsoon period with peak emergence from October to January ,although cocoons are found in the field through out the year in very small numbers in summer to large numbers in post monsoon periods. Dash and Senapati (1980, 1982) have reported the required temperature of about 20 C and soil moisture of > 7 % for Indian Megascolecoids for reproduction .Maximum population size in North-East has been observed in wet season except some species peaking in winter (Bhadauria and Ramakrishnan, 1989). Studies carried out in some African sites (Lavelle, 1983) indicate peak cocoon production in the dry spell at the end of each wet season**. Extensive similar studies in cocoon dynamics in other Indian sites will help further generalizations of the situation in Indian ecosystems and their conservation and management.**

**Secondary productivity and Energetics of Earthworm Community**

In 1960s and 1970s, the International Biological Programme (IBP) greatly stimulated research on ecosystem ecology including soil biology around the world. In these studies great importance was given to measure community metabolism, energy flow, nutrient cycling, primary and secondary productivity of different biomes around the world (Phillipson, 1971, Coupland, 1979, Breymeyer and Van Dyne, 1980). In these studies the contribution of soil fauna and microflora to ecosystem processes was given importance and some amount of data on the role of soil fauna, especially of macrofauna including earthworms were generated.The secondary production in many species populations varies seasonally and with climatic extremes. The production : respiration ratio (P/R ratio) are highest for soil animals in the tropical rangelands and in the polar region (Dash,1999 ) In these extreme climatic conditions, more energy is stored in secondary production to withstand adverse environmental conditions.The relative amount of energy being diverted to growth and reproduction have been calculated for few species populations. Lakhani and Satchell (1970) and Satchell (1971) reported some 56.02 kcal per m2.per year for *Lumbricus terrestris* populations in Europe. Lavelle (1977, 1983) reported production of 16.80 kcal per m2 per year for *Millsonia anomala* earthworm population in Lamto savanna; Ivory Coast and Nowak (1975) reported oligochate production of 58.02 kcal.m2.year and 12.03 kcal.m2.year from a partly protected and grazes pasture respectively.

In Indian pastures, Senapati and Dash (1981) reported 122.05 kcal.m2.year and 144.06 kcal.m2.year of secondary production by earthworms*. Average* P/B ratio for earthworms is 2.4 to 4.5 for ungrazed and grazed pastures respectively in India (Dash et al.1974,Senapati and Dash, 1981) in comparison to the P/B ratio of 1.2 to 2.6 in earthworm populations in Lamto savanna (Lavelle, 1977). Nowak (1975) reported P/B ratio of 0.9 to 1.3 for earthworms in temperate climate of Europ*e.*

*In* tropical pastures the secondary production of earthworms was about 5% and 3% of the net primary production respectively in grazed and ungrazed pastures. In the same Indian pastures the tissue growth amounted to about 95% and cocoon production to about 5 % of secondary production of earthworms. Of the total assimilated energy by the earthworm populations, about 20-27 % was stored in body tissue and about 2 % was spent in cocoon production. The growth rate of earthworms is a function of age and body size in a particular ecosystem and it was estimated to be generally 10 mg.g body weight.day and 7mg.g body weight.day respectively for worms weighing <150 mg and 200-700 mg during the rainy season (Dash, 1987). Several factors like food, temperature, habitat conditions, species and life cycle pattern influence growth and activity of earthworms. Since earthworm populations account for about 80 % of the total soil faunal biomass in tropical pastures, it has been estimated that secondary production of soil fauna may account for 7-10 % of the net primary production in tropical pastures.This indicates their activity level and importance (Dash, 1999). **However there is paucity of research work in this aspect in different land-uses in Indian ecosystems to make generalizations.**

The most commonly measured parameter in earthworm community energetics is the total assimilation, energy spent in respiration, mucous production and energy stored in tissue growth and reproduction. Considering these aspects only, the energy flow in earthworm community and even through the total faunal biomass will not be more than 15-20% of the total energy flow in the decomposer system,( Dash et al,1974,Petersen and Luxton,1982, Dash,1999 ).However, soil biologists generally agree that this is partially true (Huhta,2007). Soil biologists usually claim on the basis of many studies that the soil fauna contribute to decomposition several times more than their metabolism by stimulating the microbial activity.Their consumption and interaction with microflora is important (Dash et al., 1985, Lavelle, 1988). The earthworms being the dominant of soil fauna contribute significantly to this process.

In three grasslands, two lowlands and one upland in Orissa, the oxygen consumption through metabolism by earthworm community per m2 amounted to about 1205kJ, 1206kJ and 1440 kJ of energy respectively. The annual energy output in mucous production amounted to 2377 kJ, 2378kJ and 573 kJ per m2 respectively. The annual production of earthworm tissue was 678 kJ, 678 kJ and 511 kJ per m2 respectively (Dash and Patra,1977, Senapati and Dash,1981,1983). The earthworm community utilized about 13% and 16% of the net primary production in lowland and upland respectively .This estimate was based on only the assimilated energy by the earthworm community. The annual consumption would be much greater (Dash,1987)) These studies indicate that the P/B ratio is about 20 % and 28 % and Respiration/Assimilation ratio is around 80 % and 71 % in grazed and ungrazed pastures respectively. This type of study has not been done in other land-uses in India and hence comparison is not possible.

Senapati (1994) has worked on the energy budget of an epigeic earthworm, *Drawida bolaui* (adult size about 4 cm ),a vermicomposting species and, *Polypheretima elongata* (adult 50 cm),an endogeic species and found that the epigeic worm utilizes 2.5 kJ per g dry weight per day but the endogeic worm uses only 0.6 kJ per g dry weight per day. **Energetics study at species level is important for land-use management and waste land reclamation.**

**Bioturbation activity by earthworms**

Earthworms drag leaves into their burrows, degrade the litter and feed on fragments(Darwin,1881) and bring large amount of soil from deeper layers to the surface by depositing castings.The amount of litter burial in burrows and amount of soil turn over depends upon type of letter,soil and habitat,geographical region and earthworm *species i.e*. epigeic, anecic, and endogeic .

The litter bag studies done in Europe and North America ( Kurcheva,1960,Crossley and Witkamp,1964, Dash and Cragg,1972, Standen,1978) have established the role of soil fauna in the breaking down of litter and decomposition process and the weight loss of litter in control mesh bags is 2.5 times greater in comparison with limited access litterbags (Kurcheva,1960, Edwards and Heath,1963 ,Witkamp and Crossley, 1966).The litterbag studies are useful to measure the disappearance and comminution of litter but not the rate of decomposition. However these studies are still popular (Vedder et al., 1996, Heneghan et al., 1999, Kandeler et al., 1999) and provide valuable information. These studies have contributed greatly to the understanding of the role of microarthropods in the decomposition process. Earthworms play important role in the initial process of leaf litter fragmentation. Earthworms consumed more oak and beech litter than all the soil invertebrates taken together in European temperate forest soils (Edwards and Heath, 1963). By using leaf discs they found that earthworms were eating freshly fallen oak and beech leaves.The rate of breakdown of litter depends upon the type of litter. Apple leaves were consumed easily than oak leaves (Raw, 1959) and litter feeding earthworms like *Lumbricus castaneus and Eisenia foetida* produced casts, which were fragmented leaf litter. On the basis of data available in European forest sites, Satchell (1967) calculated that in a temperate deciduous woodland with a leaf fall of 3 ton per ha per year and earthworms consuming 27 g of leaf litter per day, the entire annual leaf fall would be consumed by the worms in 3 months**.**

Habitat preference studies by earthworms (Singh, 1997), gut loading and feeding rate of earthworms (Dash et al., 1984, 1986) and litter preference studies in laboratory (Kale and Krishnamoorthy, 1981), and quantitative study of litter fall and nutrient return in oak forest in Himalaya (Pandey and Singh, 1981) and litter dynamics and microbial associations in *Acacia auriculiformis* plantations in Kerala (Sankaran et al., 1993) were done in India.

The relationship between the adult worm biomass and their gut contents was found to be positively significant. Gut loading time for different earthworm species was experimentally studied and estimated in five species of Indian earthworms found in pastures, crop fields and mixed woodlands.The gut loading time varied 2 h 15 min. to 10h, depending on the size of the species and other factors. The gut filling time by an adult worm was estimated and found to vary from 2.4 times to 10.6 times per day in different species using the same type culture material. They estimated that five species of earthworms ingested about 15 kg of soil and litter material per m2 per year and this amounts to about 7 % of the total top soil and litter available on the site (Dash et al., 1984, 1986).**This type of study will have importance in understanding their role in different land-uses in India**.

Bioturbation in soil includes soil turnover by soil fauna, especially by earthworms. Satchell (1967) estimated that cast production in temperate sites would amount to 10-89 tons dry weight per ha per year.Edwards and Lofty (1977) have estimated that worm cast production ranges from 2 to 247 tons per ha per year in many sites in the world.

Studies done in Indian grasslands (Dash and Patra, 1979) show cast production of 77 tons per ha per year and maximum and minimum amount of cast production occurred respectively in rainy season and summer. Bhadauria and Ramakrishnan(1991) estimated 20 tons,35 tons,40 tons, respectively of cast production in 5 year old pine, 35 year old pine forest, and sacred grove in North-East of India. The cast production was positively correlated to the earthworm biomass in the sites and to the wet season. Kollmanspergar (1956) working on mountain savanna in Cameroons estimated 207 tons of cast production per ha per year. The high rate of soil turnover provides with stone free soil layer of about 15 cm deep on the soil surface (Edwards and Lofty, 1977**). Estimation of cast production in different land uses would indicate the**

**functional role of earthworms and this type of study in the different land-uses in India have not been made.**

From earlier studies in tropical soils (Nijhawan and Kanwar, 1952) and in temperate soils (Guild, 1952, 1955, Low, 1955,Petersen and Luxton,1982)), it is known that earthworm casts contain more water soluble aggregates than the surrounding soils and a soil rich in aggregates remain well aerated and drained.Burrowing activity of earthworms increase soil aeration. Earlier studies in temperate soils (Guild, 1952, 1955) found that soils with earthworms drain from 4 to 10 times faster than soils without earthworms. Lavelle et al.( 1996) have found that earthworms ingest on the average three times their body weight in the adult stage in tropical soils. In Indian pasture soil, Dash et al(1984,1986)estimated that *Drawida willsi*,*D.Calebi*,Lampito mauritii and *Octochaetona surensis* worms ingested about 1 to 2 times in *Drawida species*,2 to 3 times in other two species per day. Earthworms transmit huge amount of soil, not less than 1000 tonnes (Dash, 1987, Lavelle et al., 1996) in their gut annually..

Earthworm casts are rich in nitrogeneous materials and partially digested organic matter. Satchell (1967) suggested that the soil particles in worm casts are stabilized by accumulation of polysaccharide gums produced by intestinal micro-organisms. Casts contain more nitrogen than the surrounding soil and casts provide good substrate for colonization and growth of micro-organisms. The increase in the amount of nitrogen in worm casts and soil with earthworm poupulations may be due to decay of dead worms, due to their nephridial excretion and mucous secreted by them. Experimental studies indicate that the nitrogen added to soil by a single adult dead *lampito mauritii* can yield as much as 30 mg nitrogen and on the basis of above estimation, a population of 2 million earthworms per ha in a tropical grassland could yield the equivalent of about 60 kg nitrogen per ha. Taking all the sources of nitrogen production by worms i.e. dead tissue, mucous production and nephridial excretion,an earthworm population might be contributing 180 kg of nitrogen per ha. per year (Satchell, 1967, Dash, 1999).The carbon: nitrogen ratio (C/N ratio) of freshly fallen litter is about 25:1 for elm, 28:1 for ash, 38:1 for lime, 42:1 for oak ,44:1 for birch 91:1 for Scots pine (Wittichi,1953). Plants can not assimilate mineral nitrogen unless the C/N ratio falls down to the order of 25 to 20 : 1. Many studies show that the C/N ratio in soils with litter is brought down to less than 25: 1 by the intervention of earthworms (Senapati and Dash, 1982, Ndegwa and Thompson, 2000)).

**Earthworm interaction with microflora and microfauna**

Soil biologists agree that microorganisms are the primary decomposing agents in natural decomposer systems .Dash et al.(1979,1985) isolated 16 species of microfungi from earthworm gut and 7 species of microfungi from freshly laid wormcasts.By carrying out laboratory experiments, they found that earthworms grazed over and digested eight species of microfungi.They also found the thick-walled spores surrounded by multilayer cleistothecium or perithecium of *Thievia vasinfecta* and wrinkled spore coat of *Neocosmospora vasinfecta* were not digested and laid in the worm cast. The worm casts are the loci for dissemination of some species of microfungi. Analysis of gut contents for microfungal composition, soil mesofaunal and microfaunal composition, plant litter, soil turnover, gut enzymes and digestive capability of five grassland earthworms showed that the worms digested microfungi,predated over nonparasitic nematodes, utilized plant litter and a gradient exists with respect to the digestive capability of the different regions of the gut ( Dash et al.1979, 1980, 1985).Other workers have also worked on earthworm and microflora interactions and found that worms utilize microfungi and soil nematodes as food(Senapati,2002, Tiunov and Scheu, 2000 , Dominguez et al., 2003 ) .The ingestion of fungal material by adult population of five Indian species (epigeic and anecic),i.e. *Drawida willsi*, *Drawida calebi*, *Lampito mauritii*, *Octochaetena surensis, and Perionyx millardi* were measured and found to be 176.27mg, 489,59 mg, 1585.47 mg, 3794.62 mg, and 26.16 mg per m2 per year respectively .On the basis of assimilation efficiency, fungal biomass assimilated by the adult populations were respectively 137.49,264.38,903.72,1328.12 and 22.5 mg. They estimated that the worms ingested about 7 % of the total fungal biomass available as standing crop and assimilated about 3 % of the total fungal standing crop.

In experimental studies, Dash et al. (1979) have found that earthworms feed mainly on non-parasitic nematodes and Dominguez et al. (2003) have found significant reduction in the numbers of bacterivore nematodes as sewage sludge passed in earthworm gut. Earthworms inoculate the soil with micro-organisms and worm casts become foci for dissemination of soil micro-organisms. Besides earthworms, mesofauna like enchytraeids, micro-arthropods also play important role in grazing over micro-organisms and as agents of dissemination of micro-organisms Maximum number of microfungal species occur in the fore gut gradually decreasing in the mid-gut and hind-gut with minimum numbers occurring in freshly laid cast(Dash et al.1984,1986). The grazing activity over micro-organisms perhaps prevent ageing and enhance growth of microorganisms in soil(Dash et al.,1985),The amount of ingested material varied from species to species. Analysis of the gut of earthworms and enchytraeids showed a wide variety of enzymes including cellulase (Mishra and Dash, 1980).Haynes et al. (2003) have found in experimental studies using *Aporretodea caliginosa*,an endogeic species and *Lumbricus rubellus*,an epigeic species that the feeding habits between epigeic and endogeic earthworms differ and likely to greatly influence the physical and microbial properties and nutrient availability in casts.

**Interaction studies in agro- systems and different land uses may provide valuable information which can be profitably used for land use management. The microbial biomass, faunal biomass, their interaction and their relation to soil organic carbon, total nitrogen and total phosphorous are important indices to assess the status of health of soil.**

**Agro-pesticides and their effect on earthworms**

In present agricultural practices , organochlorine, organophosphates, carbamate and metal containing chemicals are used to control agricultural pests. Although earthworms are non-targeted animals but their activities are affected. Laboratory studies on Indian earthworms show that LC 50 values based on log dose vs probit mortality indicate differential tolerance in the order *of Lampito mauritii > Drawida willsi >Drawida calebi >Octochaetona surensis ,all* epigeic or anecic species *for monocrotophos; the tolerance order for fenitrothion is Lampito mauritii > Drawida calebi >Octochaetona surensis > Drawida willsi (Patnaik and Dash, 1990)* .Worms become ureotelic and ammonotelic due to starvation with increasing trend of excretion with monocrotophos exposure ( Patnaik and Dash,1991). Cholinesterase activity of nerve and muscle tissues of *Lampito mauritii and Drawida calebi* were inhibited in both short term and continuous exposure to monocrotophos and fenitrothion. The recovery potential varied between species (Patnaik and Dash, 1992, 1993).Panda and Sahu (1999),) studied effects of malathion and accumulation on the growth and reproduction of *Drawida willsi* under laboratory conditions and found that growth was inhibited in the first two weeks of application of the pesticide but worms recovered and normal growth and reproduction occurred after 105 days of application of malathion. **Comparative toxicity data based on the effect of agrochemicals on Indian earthworms are not available from different areas regarding choice of test species and to extrapolate laboratory data to land-uses .However, *Lampito mauritii*, because of its common occurrence will be suitable as the test species of choice for toxicity studies.**

Earthworms deposit and also excrete cadmium, cobalt, mercury, zinc, copper and lead in their tissues (Beyer and Cromartle,1978, Beyer et al.,1987,Marinussen et al.,1997, Panda et al.,1999, Nahmani et al.,2003 ).Panda et al.(1999) worked on the accumulation and effect of zinc on the growth, reproduction and life cycle *of Drawida willsi and found that earthworms were able to regulate their body content of zinc within a range of 116-125 mg per kg(dry weight) in 200-400 mg per kg Zn-treated soil. Reproduction and completion of life cycle was significantly affected negatively when Zn concentration in soil exceeded 200 mg per kg.* Nahmani et al. (2003) worked in 11 sites of grasslands, cultivated soils, poplar plantations to a gradient of Zn, Cd, and Pb contamination and found that metal pollution decreased density *of* earthworms and also reduced species richness. *Aporrectodea caliginosa* and *Allolobophora chlorotica* appeared to be most sensitive to heavy metals.

Although comprehensive data base on the effect of pesticides, and heavy metals on *earthworms are yet to develop but in* general it is now known that earthworms try to overcome the stress by increasing mucous secretion, reducing borrowing activity and increasing reproduction.

***Crop productivity and Wasteland Reclamation using Earthworms***

Production and decomposition are two main life supporting activities and these processes can be understood well by understanding the soil food web and nutrient cycling .The production and decomposition processes are related to organic matter input and inorganic fertilizer input, nutrient release in the context of soil food web and processes. Earthworm species diversity and community structure are significantly influenced by land-use-land cover changes (Blanchart and Julka, 1997; Bhadauria et al., 2000, Bhadauria and Ramakrishnan, 2005, Maikhuri et al., 2005, 2008, Kale and Dinesh, 2005).Many invertebrates have been used as indicators to assess sustainable land use (Paoletti, 1999).Bhadauria and Ramakrishnan(2003,2005)found earthworm species diversity are significantly influenced by land use-land cover changes.The epigeic species,*Bimastus parvus* and *Lennogaster yeicus* dominated the agroecosystems in central Himalaya probably due to higher input of farmyard manure. Earthworm population was high in primary forests with endemic species. Earthworm distribution is dependent upon litter and organic matter input rates and their chemical characteristics associated with land management practices. Surface earthworm cast production was monitored during maize cropping seasons and subsequent fallow phase by Norgrove et al (2003) and they found that slashing the vegetation caused a severe decline in cast production irrespective of the fact whether the plots were cropped afterwards or not. Significantly lower cast production occurred when mulch was removed by burning than when it was removed by mechanical means. Under shifting agriculture in north-east India, earthworm population density declined significantly after slashing and burning (Bhadauria and Ramakrishnan, 1989). Understanding these processes is important for landscape management and waste land reclamation by using earthworms.

In a Macrofauna research project funded by European Union over 7 year period scientists conducted 16 experiments in Peru, Ivory Coast, India and Australia in six great groups of soils to study the effect of earthworm inoculation on plant production in field level and in green house studies. Brown et al; (1999) found that the overall average increase in shoot and grain biomass in plants due to earthworm inoculation was + 56.3%_+9.3 %( SE) and 35.8%_+8.9 %( $P<0.07$ and $P<0.08$ respectively). Highest biomass increase was observed in soils with sandy texture, poor in organic matter, and a moderately acid pH. They also observed that Earthworm biomass of around 30 g per m2 or more was required to promote increase of more than 40% grain yield. In Indian sites in south, the most promising earthworm species were D*rawida willsi* epigeic-anecic) *andPontoscolex corethrurus (endogeic).* It is important that local adapted species at sustainable number and biomass are inoculated in the field and allowed to establish with proper management practices and once establised, they will provide long-lasting benefits. Senapati et al (1999) suggested a graphical conceptual model for management alternative for earthworm technology. .They reared *Pontoscolex corethrurus* in specific culture beds using low and high quality organic material and produced about 12,000 worms (1.6-2.8 kg live weight) per m2 per year. They inoculated earthworms with proper management practices in tea gardens and found significant increase in tea production (Giri, 2006).

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Plant influences on native and exotic earthworms during secondary succession in old tropical pastures were studied by Leon and Zou (2004) and they found that land –use changes drastically altered earthworm communities in Puerto Rico. Native species were often lost and few exotic species, such as *Pontoscolex corethrurus*, rapidly prevailed when tropical forests were converted to pastures. In green House studies, they observed that the shift in vegetation from grass to woody plants promoted the decrease in the density and biomass of the exotic species during secondary succession in old tropical pastures. This type study is useful for wasteland management.

Earthworms are considered **"keystone organisms** "in many terrestrial ecosystems as they are capable of affecting nutrient dynamics by altering soil physical, chemical and biological properties.Studies on their spatio-temporal variation in different land-uses will provide clues of their colonization pattern and possible utilization in wasteland reclamation.

Many studies in European temperate climates (Whalen and Costa, 2003, Muys et al., 2003, Scheu, 2003) have shown that earthworms play key roles in nutrient cycling, modifying soil porosity and aggregate structure, controlling soil microbial communities, plant growth. Piearce et al (2003) have used paper mill sludge and earthworms in land restoration. An experiment was conducted to investigate the effect of three earthworm species, epigeic-*Lumbricus rubellus*; anecic- *Lumbicus terrestris* and endogeic-*Aporrectodea* calliginosa tuberculata and 15 N-labelled crop residue and from soil organic matter to study effect of earthworms on bacterial community and nitrogen mineralization by Postma-Blaauw et al. (2006) and they found that the epigeic and anecic species enhanced mineralization of crop residue where as the endogeic had no effect. The epigeic and endogeic eartheworms enhanced mineralization of soil organic matter and the anecic earthworm did not play much role in it.The interactions between different earthworms species affected the bacterial community and the net mineralization of soil organic matter. They concluded that knowledge of these interaction studies can be made useful in the prevention of nutrient losses and increases soil fertility in agricultural systems.

In a study involving microbiological and physico-chemical characteristics of tropical forest, grassland and cropfield soils by Prasad et al. (1994) show that conversion of natural forest led to reduction of soil organic C, total N, total P, microfungal biomass and total microbial biomass C, N and P over a 30-50 year period and ultimately it led to the loss of biological stability of the soil.Taking clues from european and american studies, inoculation of earthworms with proper feed material may help restoration of stability of degraded soils.

**Identification of epigeic, anecic and endogeic"keystone"earthworms in different land-uses in India will be helpful for wasteland reclamation. Studies in these lines will be profitable. The introduction of exotic species will create problems and therefore, generally should be avoided.**

**Vermitechnology :**

Earthworms (verms) are now utilized for (i) vermifeed as protein source for fish and poultry;(ii) for large scale vermin-culture for production of wormcast, which are utilized as vermin-manure and for water holding substrate for growth of edible mushrooms, (iii) for field inoculation of the desired species of earthworms for increasing insitu plant productivity, and waste land reclamation; (iv) for converting municipal organic waste into manure through vermi-composting and other uses. The technology involving utilization of earthworms into the above cited processes is called vermitechnology.

**Vermiprotein:** Earthworm tissue contains more than 50% proteins on dry weight basis (Dash et al, 1977).Essential amino acids are available in their body tissue. In an experiment earthworm dry tissue as feed material for Japanese quails, and chicks was fed and evaluated as substitute for fish meal. Two diets were used, one a control ration with 9.4% fish meal and a test ration with 9.4% gut cleaned earthworm tissue meal and the ratio was adjusted in such a way that both rations contained 23% protein.The mean weight gains and growth rate were measured .The mean weight gain for broilers were 1.12kg and 1.17 kg, feed consumption was 2.528 kg and 2.524 kg for 46 days, feed conversion ratio was 2.263 and 2.154 and mean growth rate(kg per day) was o.024 and 0.025 respectively for fish meal and earthworm meal ration.(Das and Dash,1989,1990 )

Cultivation of edible mushroom, *Pleurotus sajor caju* using wheat supplement in a paddy straw substrate was tested and compared with earthworm casts supplementation to replace wheat. Cellulose and water were more efficiently used by the mushrooms when worm casts were used and it resulted in increased mushroom yield (Dash and Das, 1989). This type of study on different earthworm species can provide useful data for possibility of use of earthworms more extensively (**Figure** 1).

**Vermicomposting:** The science of vermicomposting took shape from mid-20$^{th}$ cnentury and the first plant was started in Hollands landing, Ontario, Canada(Appelhof,1980,1981).Since then the technology has become very popular all over the world and has gone modification keeping the availability of desired earthworm species and many other conditions(Hartenstein et al.,1979,Collier and Livingstone,1981,Dash and Senapati,1985,1986, Singh,1997,Ndegwa and Thompson,2000,Gajalakshmi et al.,2001, ,Frederickson and Howell,2002, ,Arancon et al.,2002,2003a,b,Chaudhuri et al.,2003,Pizi and Novakova,2003, Tripathi and Bhardwaj,2004,Loh et al.,2005, Garg et al.,2006,Sen and Chandra,2007,Pramanik et al.,2007,Suthar,2007,Clarke et al.,2007,Tognetti et al.,2007,Padmavathiamma et al.,2008).
Most of the recent papers deal with three earthworm species , *Eudrilus eugeniae, Eisenia foetida, Perionyx excavatus*, for vermicomposting .The changes in C/N ratio, C/P ratio, concentration of N, P and K ,Phosphatase activity in worm casts, microbial interactions, and some other parameters have been taken as criteria for judging the efficiency of earthworms in the vermicomposting process. Reproductive fitness of the worm, growth, mortality factors based on feeding pattern (Reinecke and Viljoen (1990) have also received attention of research workers.

In recent times importance is given to local and endemic species due to outbreak of foot-and-mouth disease and fungal pathogens in Europe related to earthworm import (Hendrix and Bohlen (2002).
The endemic species are also important for wasteland reclamation, plant productivity etc.

The exotic African species, *Eudrilus eugeniae* is being used in many centres in India. There is serious threat of invasion of this species to natural ecosystems causing ecological problems for endemic species. Another exotic species *Eisenia foetida* is also used in India. This species was introduced before India's independence and this species has been colonized in many natural ecosystems.Bhadauria and Ramakrishnan (2005) have found many exotic species in North-east and Central Himalaya. The ecological implications have not been fully assessed. However, some research work for vermicomposting in India has given importance to local species (Dash and Senapati, 1985, 1986, Dash, 1994, 1999,Singh,1997,Gajalakshmi et al., 2001, Maity et al, 2008).The data available indicate that a number of Indian species may be suitable for vermicomposting of organic portion of urban waste, agricultural waste, animal dung, water hyacinths, organic based industrial wastes from food processing plants, sugar mill, paper mill, kitchen waste etc.,and for field inoculation, as vermifeed and related purposes.

Research on screening of potentiality of Indian earthworm species for vermitechnology purpose should be considered a thrust area for research funding**.** Selection of earthworm species should emphasize on amount of biomass consumption and rate of consumption and rate of growth, reproduction potential, adaptability of the species etc.In general worms should be capable of inhabiting in high percentage of organic material, high adaptability to environmental conditions, with low incubation period (period of inactivity after initial inoculation to organic waste) and high fecundity, and short maturity time (reaching adulthood) etc.

**Table**-3 gives comparative account of the vermicultural characteristics of some Indian earthworms including, *Perionyx excavatus*, *Eisenia foetida* (= *fetida*) and the exotic, *Eudrilus eugeniae*.**There is need of research to standardize the bioreactor conditions, type and quality of organic waste-substrate and type of amendments to be made, biochemical analysis of vermicompost and a protocol for use in the field application for crop productivity.Indian earthworm species like *Perionyx excavatus*, *Lampito mauritii*, *Drawida willsi*, *Drawida bolui*, *Perionyx sansibaricus*,are considered suitable for vermicompsting of organic wastes.Eisenia fetida is also widely used and other locally available epigeic and anecic species should be studied for their vermicocmposting purpose keeping the criteria discussed in this paper in view.**

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Table 1 Earthworm resources in India

About 500 species

| Sl. No. | FAMILY/ GENUS | HIMALAYA EAST | WEST | INDO GENETIC PLAIN | DECCAN PENNISULA |
|---|---|---|---|---|---|
| 01. | Acanthodrilidae | | | | |
| | Pontodrilus | | | | |
| | Pletellus | + (Peregrine) | | + | + |
| 02. | Aimidae | | | | |
| | Glyphidrilus | + | + | + | + |
| 03 | Eudrilidae | (Restricted to Ethopain regiona, recorded from Poona considered exotic in India) | | | |
| | Eudrilus | | | | |
| 04 | Lumbricidae | (Europe and North America, introduced to India) | | | |
| | Lumbricus | + | + | +(?) | + |
| 05 | Megascolecidae | | | | |
| | Amanthus | (Peregrine) | | | |
| | Comadrilus | | | | + |
| | Lampito | *L. Mauritii* is widely distributed | | | + |
| | Lennoscolex | | | | + |
| | Megascolex | | | | + |
| | Metaphire | | | | + |
| | Nelloscolex | + | | | + |
| | Notoscolex | | | | + |
| | Perionyx | + (*P.execavatus* & *P. sansibaricus* widely distributed) | | | + |
| | Pithemera | (Peregrine) | | | |
| | Polypheretima | (Peregrine) | | | |
| | Tonoscolex | + | | | + |
| | Troyia | | | | |
| 06 | Moniligastridae | | | | |
| | Desmogaster | +(?) (Peregrine) | | | |
| | Drawida | + | + | + | + |
| | Moniligaster | | | | + |
| 07 | Ocnerodrilidae | | | | |
| | Curgiona | | | | + |
| | Deccania | | | | + |
| | Ocnerodrilus | + | | + | + |
| | Eukerria | | | | |
| | Malabaria | | | + | + |
| | Thatonia | | | + | + |
| | Gordiodrilus | (Peregrine) | | +(?) | + |

| | | | | | |
|---|---|---|---|---|---|
| 08 | Octochaetidae*<br>(26 genera) | | | | |
| | *Bahlia (1 sp.)* | | | + | |
| | *Barogaster (3)* | | | | + |
| | *Calebiella(1)* | | | | + |
| | *Celeriella(7)* | | | + | |
| | *Chaetocotoides(1)* | | | + | |
| | *Dashiella (1)* | | | | + |
| | *Dichogaster (5)* | + | + | + | + |
| | *Eudichogaster(6)* | | + | + | |
| | *Eutyphoeus(22)* | + | + | + | + |
| | *Hoplochaetella (18)* | | | + | |
| | *Karmiella(1)* | | | | + |
| | *Konkardrilus(4)* | | | | + |
| | *Kotegeharia(1)* | | | | + |
| | *Lennogaster(6)* | | | | + |
| | *Mallehula(1)* | | | | + |
| | *Octochaetona(15)* | | | + | + |
| | *Octonochaeta(1)* | | + | + | + |
| | *Octochaetoides(1)* | | | + | + |
| | *Pellogaster(3)* | | | +(?) | + |
| | *Priodochaeta(1)* | | | +(?) | + |
| | *Priodoscolex(1)* | | | | + |
| | *Ramliella(5)* | | | | + |
| | *Rillogaster(2)* | | | | + |
| | *Scolioscolides(1)* | + | | | + |
| | *Travoscolidae(4)* | | | | + |
| | *Wahoscoles(9)* | | | | + |

* Number of species in parenthesis

Table 2. Density, biomass and annual production of earthworms (per $m^2$) in different Indian sites

| **Land use/ ecosystems** | **Diversity** | **Density** | **Average/ Range Biomass (wet weight, g)** | **Average / Range Production (g)** | **Trends** | **References** |
|---|---|---|---|---|---|---|
| Pastures, Berhampur, Orissa | **Two Species** *Lampito mauritii, Ocnerodrilus occidentalis* | 18-88 | 6-61 | 126-140 | Peak density after monsoon in early winter | Dash and Patra (1977) |
| Pasture,Bangalore, Karnataka | | 25-936 | | | | Kale and Krishnamoorthy, (1978) |
| Orchad, Bangalore, Karnataka | | 38.2-420.5 | | | | Kale and Krishnamoorthy, (1978) |
| Barren land , Bangalore, Karnataka | | 138.6-398.1 | | | | Kale and Krishnamoorthy, (1978) |
| Arable land, Bangalore, Karnataka | | 51.9-274.4 | | | | Kale and Krishnamoorthy, (1978) |
| Pine woodland, Shillong, | | 8.8-52 | 4.4-9.4 | | | Reddy and Alfred, (1978) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Meghalaya | | | | | | |
| Grasslands, Sambalpur, Orissa | **Five Species** *Drawida calebi, D. willsi, Lampito mauritii, Octochaetona surensis, Ocnerodrilus occidentalis* | - | 9.78-77.68 | 134 | Peak density immediately after monsoon in early Winter | Dash and Senapati (1981) |
| Mixed Deciduous forest, Sambalpur, Orissa | **Four Species** *Lampito mauritii, Drawida calebi,Rameila bishambari, Pellogaster bengalensis* | 24-131 | 7-28.5 | 78 | Peak density in October | Mishra and Dash (1984) |
| Mixed woodland, Solan , Himachal Pradesh | | 30.4-118.4 | | | | Julka and Mukherjee, (1984) |
| Humid Tropical deciduous forest, Andhra Pradesh | **Five Species** *Amynthas alexandri, A. diffringens, Metaphire posthuma, M. houlleti, Dichogaster sp.* | 315 In different microsites in the forest: 28-281 | - | - | Two peaks during and end of the rainy season | Reddy (1987) |
| Shifting agriculture in North-Eastern India (Nangpoh) | **Three Species** *Megascolides antrophytes, Drawida assamensis, Nelloscolex strigosus* | 68 | - | - | Immediately after Rainy season | Mishra and Ramakrishnan (1988) |
| Shifting agriculture in North-Eastern India (Shillong) | **Five Species** *Amynthas . diffringens, Drawida assamensis,Eutyphoeus festivus, Nelloscolex strigosus, Tonoscolex horaii* | 4-47 in cropping phase, 50 in fallow phase | - | - | Peak density during rainy season except *Amynthas . diffringens* , which peaks in winter | Bhadauria and Ramakrishnan (1989) |
| Upland irrigated rice field, Sambalpur, Orissa | **Five Species** *Drawida calebi, D. willsi, Lampito mauritii, Ocnerodrilus occidentalis, Octochaetona surensis,* | 1399 | - | - | Peak density in August-September (monsoon) | Senapati (1992) |
| Pasture, Kumaon Himalaya | **Three Species** *Amynthas . diffringens, Amynthas alexandri, Eisenia fetida* | 138.8 | 25.2 | - | Peak density in the end of rainy season (October-December) | Kaushal and Bisht (1994) |
| Cultivated soil , Kumaon Himalayas | **One species** *Amynthas alexandri* | 58.4 | - | - | Peak density during rainy season | Kaushal etal., (1995) |
| Sites in Varanasi, UP | **Eleven Species** Dichogaster bolaui, Eutyphoeus incommodus, E. nicolsoni,E. | | | | Grass land, cultivated soil, non-cultivated soil, garden | Singh (1997) |

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|---|---|---|---|---|---|---|
| | waltoni, Octochaetona surensis, Ramiella bishambari, Amynthas morrisi, Lampito mauritii, Metaphire posthuma, Drawida calebi, Glyphidrilus sp. | | | | soil, sweage soil | |
| | | | | | | |
| Village landscape, Central Himalaya (mid elevation) | **Eight Species** *Bimostus parvus, Octolasion tyrtaeum, Octochaetona beatrix, Amynthas corticis, Eutyophoeus festivus, E. nanianus, E. waltonii, Drawida sp.* | Climax forest: 526, Mixed forest: 309, Five year old pine: 287, 40 year old pine: 940, grass land:353 | - | - | Peak density during rainy season | Bhadauria and Ramakrishnan (2000) |
| Cropland,Pasture,Garbage sites,Jharkhand,Ranchi | **Twelve Species Lampito mauritii,Drawida calebi,D.bolaui,D.affinis,Metaphire planate,M.posthuma,Perionyx sansibaricus,Ocnerodrilus occidentalis,Lennogaster bengalensis,Glyphidrilus tuberosus,Pontoscolex corethrurus.Pellogaster bengalensis.** | Cropland 2585 (75-7600) | 11.32 (0.57-30.01) | | Peak density in August(rainy season) Cropland only one species-Ocnerodrilus occidentalis | Sinha et al(2002,2003) |
| Village landscape, Garhwal Himalaya (mid elevation) | **Seven Species** *Amynthas corticis,Drawida nepalensis, Allbophora parva, Eutyphoeus pharpingianus, Octochaetona beatrix, Perionyx sp., Lennogaster pusillus,* | 108-247 in forests, 89-235 in agro-ecosystems | - | - | Abundance in pine forest-higher but low diversity compared to oak forest | Sinha et al., (2003) |
| Nandadevi Biosphere, Central Himalaya | **Eight Species** *Lennogaster pusillus,Metaphire houlleti, M. anomala, Ocnerodrilus occidentalis,Dendrodrilus rubidus, Aporrectodea calliginosa, amynthus corticis, Drawida nepalensis* | ***Lower elevation***: Home garden-100, pine forest:5-10, oak forest: 5, Irrigated agriculture-5, Rainfed agriculture: 5-25 ***Higher elevation*** Home | ***Lower elevation*** Home garden:3, Oak forest: 2, Pine forest:2, Rainfed agriculture:1, , ***Higher elevation*** Home garden:35,Alpine pasture:7, Alpine forest: | - | Peak density in the end of rainy season-winter | Maikhuri etal., (2008) |

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|---|---|---|---|---|---|---|
| | | garden:10-150,Alpine pasture:5-25, Alpine forest: 10-15 | 10 | | | |
| Nilagiri, Biosphere , Kerala | **Fourteen Species** *Dichogaster affinis, Drawida modesta, D. barwelli impertusa, D.ghatensis, D. grandis, Glyphidrilus annandalei, Haplochetalla sp., Lampito mauritii, Megascolex insignis, M. triangularis, Octochaetona beatrix, Parryodrilus lavellei, Plutellus variabilis, Pontoscolex corethrurus* | Moist deciduous forest:215, Degraded forest:2, Teak forest with plantation:84, Annual crops:24, Home garden:46, Poly culture farm:60, Arecanut with annuals:27, Arecanut with perennials:55, Coconut with perennials :294, **Plantations** Arecanut:157, Coconut:36, Rubber:50, Cashew:150, Teak:121 | - | - | - | Chandrashekara etal., (2008) |

Table 3. Vermiculture characteristics of some Indian earthworms suitable for vermicomposting

| Species | Soil temperature for maximum growth | Age for cocoon production (weeks) | Upper limit of soil temperature tolerance (ºC) | Vermi-stablization time (weeks) | No of young / cocoon | Incubation period (weeks) | Average size, live weight (g) |
|---|---|---|---|---|---|---|---|
| *Perionyx excavatus* | 25-30 | 15 | 30 | 4-5 | 1-2 | 4 | 1 |
| *Lampito mauritii* | 18-30 | 8 | 30 | 3 | 1 | 4 | 1 |
| *Octochaetona surensis* | 20-25 | 15 | 27 | 8-10 | 1 | 4 | 1 |
| *Drawida willsi* | 20-25 | 8 | 30 | 3-4 | 2-3 | 2 | 0.5 |
| *Dichogaster bolaui* | 25-30 | 7 | 33 | 3 | 1-2 | 1 | 0.1 |
| *Eudrillus eugeinae*** | 20-25 | 8 | 30 | 3-4 | 2-3 | 4 | 1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Eisenia foetida* | 18-25 | 7 | 25 | 6-8 | 2-4 | 3-4 | 0.5 |

** African worm (exotic)

Fig. 1 A Conceptual Model of Management Potential of Vermitechnology