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Vermitechnology for Wasteland Reclamation, Plant Productivity and Composting: A Review in Indian Context

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ABSTRACT

This paper presents a review of the existing knowledge on the application of earthworms, both native and exotic species for waste land reclamation, increasing plant productivity with reference to tea production in Indian sites, plant growth and productivity in Indian and world sites and application of vermicompost for increased plant growth in some Indian sites. The paper identifies Indian species of earthworms to be employed in vermitechnology. Based on the existing knowledge, the areas of future research and funding on vermitechnology have been identified.

Key Words: Earthworms, Native, Exotic, Land Uses, Plant Productivity, Composting, Vermitechnology

INTRODUCTION

With foundations of soil biology laid by Charles Darwin whose bicentenary birth year is being celebrated this year, the modern biologists view soil biota as the most diverse community of the planet (Dance, 2008). Darwin (1881) opened a new line of biological research on the role of earthworms maintenance of soil fertility, although Gilbert White (1789), Hansen (1877) and Muller (1878) did provide some insights in this direction. Recently Dash and Dash (2008) have reviewed the role of earthworms in tropical ecosystems, especially in different land uses in India.

Darwin described how earthworms through their feeding activities produce "vegetable mould'. Until 1950 (Kuhnelt 1950), not much work was done on soil faunal activities. Satchell (1967, 1983), with many experimental studies in European forests, highlighted the contribution of earthworms to nitrogen excretion, mucous production, and biomass turnover. Later, a positive impact of earthworms on plant productivity was shown in pot experiments carried out in Europe (Edwards and Lofty 1977, Lavelle 1988). Over the last three decades, a large number of studies on earthworm biology and ecology have been carried out in India such as studies of Dash et al. (1974, 1977, 1984, 1985, 1986), Das and Dash (1989), Dash and Das (1989), Dash and Patra, (1977, 1979), Dash (1978), Kale and Krishnamoorthy(1978, 1981), Senapati and Dash (1981,1984) and Mishra and Dash (1984) dealing with life cycle patterns, community structure and functional role of earthworms in terms of worm-cast production, nitrogen excretion, secondary productivity and energetics and earthworms-microbes-nematodes interactions, suitability of earthworms as feed material for poultry and edible mushroom production (Das and Dash 1989, 1990, Dash and Das 1989) and on performance of Indian earthworms in vermicomposting (Dash and

Senapati 1985, Dash et al. 1985, 1986). Some knowledge on role of earthworms in nutrient cycling, waste land reclamation and earthworm-land use/cover-environment relationships is also available (Giri 2006, Kale and Krishnamoorthy 1981, Sahu et al. 1988, Reddy and Reddy 1990, Sahu and Senapati 1991, Bhadauria and Ramakrishnan 1989, 1991, Bhadauria et al. 1997, 2000, Singh 1997, Dash 1994, 1999, Senapati 1993, Ismail 1997, Lavelle et al. 1996, Choudhuri and Bhattacharjee 2002, Chaudhuri et al. 2003, 2008, Bhattachajee and Chaudhuri 2002, Gajalaxmi et al. 2001, Sinha et al. 2003, Tripathi and Bhardwaj 2004, Kale and Dinesh 2005, Maikhuri et al. 2005, 2008).

In most endeavors on vermicomposting, non-native earthworms like *Eudrilus eugeniae*, *Eisenia fetida* (= *foetida*) have been emphasized. Field studies in south India indicate that *Pontoscolex corethrurus* (an endogeic species) is quite effective in restoration of degraded soils and enhancement of productivity of tree plantations (Senapati et al. 1999). This earthworm species is widely distributed, from warmer climates in southern India to cooler climates in the Himalaya in the northern part of the country (Maikhuri et al. 2005, 2008).

This article is an attempt to provide a review on role of earthworms on wasteland reclamation, plant productivity, vermicomposting and vermitechnologies.

WASTELAND RECLAMATION USING EARTHWORMS

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), leading to changes in soil food web organization and rates of primary production and decomposition. Many invertebrates have been used as indicators of sustainable land uses (Paoletti 1999). Bhadauria and Ramakrishnan (2005) explained the dominance of epigeic *Bimastus parvus* and *Lennogaster yeicus* in agro-ecosystems in central Himalaya to be due to massive input of farmyard manure. These studies indicate *Pontoscolex corethrurus* can be profitably used to restore degraded lands. However the detailed protocol has not been developed by any worker.

During secondary succession following conversion of tropical forests to pastures, Leon and Zou (2004) found that land use changes often led to loss of native species coupled with dominance of the exotic *Pontoscolex corethrurus*, with suppression of the exotic earthworm with increasing dominance of woody plants. Prasad et al. (1994) observed that conversion of natural forest led to reduction of soil organic C, total N, total P, micro-fungal 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, and, taking clues from European and American studies, suggested inoculation of native earthworms with proper feed material as a means of restoration degraded soils.

Identification of epigeic, anecic and endogeic “keystone” earthworms in different land-uses in India will be helpful in using earthworms as a tool in wasteland reclamation. Abundance and biomass dominance of P. *corethrurus* in tea garden (Senapati et al. 2002) and having the characteristics of endogeic soil eating earthworm and the various beneficial role and its contribution to the soil fertility (Barois et al. 1999, Fragoso et al. 1999, Choudhury and Bhatterjee, 2009) has proved it to be a key stone species. *Pontoscolex corethrurus* is a peregrine endogeic species introduced to India perhaps during British rule. With its dominant occurrence now in a variety of ecosystems across the country, it can be considered as a keystone species.

In the Himalayan Nanda Devi biosphere reserve, a relatively less disturbed region, Metaphire *houlleti, Lenogaster pusillus* and *Aporrectodea caliginous* are common at lower elevations and *Aporrectodea caliginous* at higher elevations, while *Amynthas cortices, Amynthas alexandri* and *Amynthas diffringens* are common in more disturbed and managed landscapes in central and eastern Himalaya (Bhadauria et al., 2000). In the absence of any studies on vermitechnology using these species, making generalization about the functional role of these species is not possible. Yet, it is clear that problems following introduction of exotic earthworms may follow ecological problems and hence their introduction should be carefully reviewed.

Norgrove et al. (2003) found that slashing the vegetation caused a severe decline in cast production irrespective of the fact whether the plots were cropped afterwards or not. Burning had a more severe impact than mechanical removal of mulch. Bhadauria and Ramakrishnan (1989) also reported similar trends in shifting agricultural landscapes in north-east India.

Patterns of spatio-temporal variation in earthworm population in relation land-use and other environmental factors is likely to provide clues about the ways earthworms could be used for reclaiming wastelands (Whalen and Costa 2003, Muys et al. 2003, Scheu

2003). Piearce et al. (2003) have used paper mill sludge and earthworms in land restoration. Postma-Blaauw et al. (2006) studied the effects of an epigeic (*Lumbricus rubellus*), an anecic (*Lumbicus terrestris*) and an endogeic (*Aporrectodea calliginosa*) on bacterial community and nitrogen mineralization and concluded that the epigeic and endogeic earthworms enhanced mineralization of soil organic matter, while the anecic earthworm was almost insignificant in this regard. The interactions between different earthworm species thus become important using earthworms as a tool for building up soil fertility.

Plant Productivity

Table 1 summarizes the role of earthworms on plant production in 80 different world sites in Europe, USA, South America, and India. In a Macro-fauna research project funded by European Union, scientists from 8 countries conducted experiments in six great groups of soils to study the effect of earthworm (13 earthworm species) inoculation on plant production. Brown et al. (1999) reported an average increase in shoot biomass by 57% and grain biomass by 36% due to earthworm inoculation in the experiments conducted in various crops like yam, rice, cowpea, tea, grass, beans, wheat, *Mimosa scabrell*a, *P. maximum*, peanuts, *B. decumbens*, *Bixa orellana*, *Bistros gasipeas*, *Eugenia stipitata*, sorghum and oats. Highest magnitude of impact observed in moderately acidic sandy soils highly depleted of organic matter and the requirement of earthworm biomass of around 30 g, m^{-2} or more for achieving at least 40% increase in grain yield.

Synchronization of release of nutrients from organic residues with crop demand is the key concern in biological management of soil fertility. With this concept in mind, a collaborative project by Sambalpur University, Parry Agro Company, and Paris University was carried out in the tea gardens in south India. Tea cultivation in India started in the year 1823. India produced 0.928 million Mg (=ton) of tea leaf in 2005, with an average yield of about 2 Mg per ha over an area of 0.52 million ha. India contributes about 28% of global tea production earning 10% of its total foreign exchange and employing 3-4 million people in this industry. Most tea gardens in south India are located in hilly terrain on highly leached and weathered soils characterized by very low levels of water holding capacity, organic matter, cation exchange capacity, and macro fauna abundance (Giri 1995, 2006). *Megascolex* sp. (epigeic-anecic) and *Pontoscolex corethrurus* (endogeic) and *Notoscolex* sp. (endogeic) were identified as the most promising species for inoculation since they were the existing tolerant endogeic earthworm species found in these more than 100 years old tea garden, and to chemical pesticides used in the tea garden. A critical density and mass of inoculant was decided to ensure successful establishment and long-lasting benefits.

Senapati et al. (1999) reared *Pontoscolex corethrurus* in culture beds containing a mix of low and high quality organic material, with a worm production rate of 12,000 worms (1.6-2.8 kg live weight) per m^2 per year. Inoculation of *P. corethrurus* together with other appropriate management practices in tea gardens followed a significant increase in tea production in experimental plots established in the tea garden of Parry Agro Industries Limited in the Anamallai and Nilgiris hill ranges (Senapati et al. 1999, 2002).

Small scale experiments were carried out with tea cuttings in the nursery at Iyerpadi. Eight treatments involving different combinations of high quality organic matter (a compost produced from urban organic wastes named Humigold (Table 2) and low quality organic matter (tea prunings) were prepared and *Pontoscolex corethrurus* inoculated along with planting of tea cuttings (Giri 1995, 2006). Soil without any input of low quality or high quality organic matter or earthworm was considered as the control set. The tea cutting cultures were cared for soil moisture level, incident light, and attack from pests, diseases and weeds. After 8 months of growth in nursery, the cuttings were transplanted in the garden. These experiments showed that the shoot and root biomass increased with individual input of low (tea pruning matter) and high quality organic matter (processed city waste organic compost named Humigold), and with the combination of both high and low quality organic matter. But the maximum impact on plant production and soil physico-chemical characteristics was observed in the set with application of both earthworms along with different quality of organic matter individually or in combination.

In this experiment, maximum enhancement of 120.6% in the shoot biomass and 108.3% in the root biomass occurred when earthworms were inoculated with proper input of organic matter. Inoculation also resulted in shortening of time required for production of transplants, from 14-16 months in normal technology to 6-7 months. Thus, earthworm inoculation led to multiple benefits viz., shortening of timeperiod required for production of transplants, increase in tea productivity and resource use efficiency, and improvement in soil fertility (Giri 2006).

Table 1. Impact of earthworms on plant productivity in a cross section of studies

Plant	Earthworm treatment (Percent change in production over control)	Earthworm Taxa involved/used	Reference and Country
Mustard, Wheat Rye, Spinach, Barley	-64 to 41% depending on crop	Lumbricids	Russel 1910; U.K.
Oats, Garbanzo, Beans, Mustard	114, 90, 22.5%	Lumbricids	Kashnitz 1922; Germany
Winter wheat	increased yields	Lumbricids	Dreidax 1931; Europe
Hay/Clover	-48 to 495% mean 150%) *Diplocardia* sp.	Various Lumbricids/	Hopp and Slater 1948; USA
Millet Lima beans Soybean Wheat	11% shoot (no significant diff.) 8% grain (no significant diff.) 248% shoot 20% grain	*A. caliginosa* / *Diplocardia* sp.	Hopp and Slater 1949; USA
Turves and grass Pastures	58-98% and 31-110%	Mainly lumbricids *A. caliginosa*	Nielson 1951;1953; New Zealand
Ryegrass, Clover and Grass	89-190%, -3% to 10% & 6-113%	*A. caliginosa*	Waters 1952; New Zealand
Crops	400 %	?	Ponomareva 1952; USSR
Barley	increased growth	*L. rubellus*/ *L. terrestris*	Uhlen 1953; Sweden
Oak and Ash saplings	26% and 37%	*A. caliginosa*	Zrazhevskii 1958; USSR
11 years old pasture	72%	*A. caliginosa*	Stockdill 1959) New Zealand
Grass, Wheat, Clover and peas	287, 111, 877 and –39% average shoot	5 lumbricid species	Van Rhee 1965; Holland
Barley	92-201%	*A. caliginosa*	Atlavinyte et al. 1968; Lithuania
17-18 yr old pasture	9-29%	Lumbricids	Stockdill and Cossens 1969; New Zealand
Fruit orchards	2.5%, 138% roots after 8 yr	*A. caliginosa*/ *L. rubellus*	van Rhee 1977; Holland
Barley	240-280% grain	*A. caliginosa*	Atlavinyte 1971; Lithuania
Pasture	10% (diff. Not significant)	*A. caliginosa*	Noble et al. 1970; Australia
Black spruce	17% top growth; -3% roots after 19 months	*A. caliginosa*/ *L. terrestris*	Marshall 1971; USA
Oats	20-50%	*A. caliginosa*	Atlavinyte and Pociene 1973; Lithuania

Table 1. Continued

Plant	Earthworm treatment (Percent change in production over control)	Earthworm Taxa involved/used	Reference and Country
Rape, Oats	18-49% shoot	*L. terrestris*	Graff 1971; Germany
Barley	78-96%	*A. caliginosa*	Atlavinyte 1974; Lithuania
Oat seedling	8.7% (21% protein) shoot	*Eisenia fetida*	Aldag and Graff 1975; Germany
Ryegrass	22% shoot at 2nd cut	*L. terrestris*	Graff and Kuhn 1977; Germany
Barley	62-269% grain	*A. caliginosa*	Atlavinyte et al. 1977; Lithuania
Barley	78-270% roots; 10-37% grain (not significant)	*L. terrestris* + *A. longa*; *A. chlorotica* + *A. caliginosa*	Edwards and Lofty 1978, 1980; U.K.
Ryegrass	10% (using exudates from containers with earthworms)	Lumbricids	Graff and Makeshin 1980; Germany
Ryegrass	-23%	*A. trapezoides*	Abbott and Parker 1981; Australia
Barley grain	4-220%	*A. caliginosa*/ *L. terrestris*	Atlavinyte and Vanagas 1982; Lithuania
Ryegrass	5-50% shoot	*A. caliginosa*	McColl et al. 1982; New Zealand
17-18 yr old pasture	9-29%	Lumbricids	Stockdill 1982; New Zealand
Oats	12-40% shoot	4 Lumbricids	Graff and Makeshin 1983; Germany
Barley	56-96%	*A. caliginosa*	Atlavinyte and Zimkuviene1985; Lithuania
Pastures	27% in shoot after 14 month; -32% roots (not significant)	*A. longa*	Springett 1985; New Zealand
Rice	4-36% shoot	*D. willsi*	Senapati et al., 1985; India
Blue stem shoots	-7% to 18%	*A. caliginosa*/*Diplocardia* sp.	James and Seastedt 1986; USA
Maize seedlings	greater emergence	*L. rubellus*	Kladivko et al. 1986; USA
Reclaimed bog	25-49% shoot	Lumbricids	Curry and Boyle 1987; Ireland
Barley	up to 514% yield	*Allolobophora parva*	Temirov and Valiakhmedov 1988; Tajikistan
Ryegrass	30% shoot after 350 days	Lumbricids	Curry et al. 1989; Ireland

Table 1. Continued

Plant	Earthworm treatment (Percent change in production over control)	Earthworm Taxa involved/used	Reference and Country
Maize, *Panicum maximum*	1 to 3.25% increase	*M. anomala*	Martin et al. 1991; Peru
Pasture	60-75% shoot in 2 years	*A. caliginosa*/*A. longa*	Temple-Smith 1991; Tasmania
Beech seedlings	Significantly higher stem biomass and N after 80 days	*Octolasion lacteum*	Wolters and Stichan 1991; Germany
Birch seedlings	200% in roots and stems after 119 days	*A. caliginosa*	Haimi and Einbork 1992; Finland
Peach palm Fruit trees	14-24% shoot 17-1357% shoot, 8-1641% Root, 6-1413% total yield	*P. corethrurus* *P. corethrurus*	Pashanasi et al. 1992; Peru
Wheat	62% grain	*A. trapezoides* and /*Microscolex dubius*	McCreadie and Parker 1992; Australia
Maize, *Panicum maximum*	24-34% shoot, 17-65% root, 18-63% total yield	*P. corethrurus*, *H. africanus* *M. anomala*, *C. zielae*, *S. porifera*	Spain et al. 1992; Ivory Coast
Wheat	39% and 13%	*A. trapezoides* and *A. rosea*	Williams and Baker 1993; Australia
Wheat and *Rhizoctonia*	11-26% shoot after 18 days	*A. trapezoids*	Stephens et al. 1993a; Australia
Pastures	0-17% shoot after 15 months	*A. longa*	Garnsey 1994; Tasmania
Cereals correlation	Correlation not significant	Various exotics, Lumbricids and others	Buckerfield and Auhl 1994; Australia
Wheat	100% shoot; 40% root	*A. trapezoids*	Doube et al. 1994a; Australia
Subterranean clover	Up to 125% shoot, 20-30% root, 5x nodules after 42 days	*A. trapezoids*	Doube et al. 1994b; Australia
Wheat	0-24% shoot, 13-42% root after 27 days	*A. trapezoides, A. rosea*	Stephens et al. 1994a; Australia
Wheat with and without take-all disease	Higher root and shoot biomass with take all; no difference without after 36 days	*A. trapezoides,* *A. rosea*	Stephens et al. 1994b; Australia
Wheat seedlings With pea straw and *Rhizoctonia*	12-35% shoot with straw; -14 to -26% without after 16 days; with *A. rosea* no effect	*A. trapezoides,* *A. rosea*	Stephens et al. 1994c; Australia

Table 1. Continued

Plant	Earthworm treatment (Percent change in production over control)	Earthworm Taxa involved/used	Reference and Country
Wheat with and without *Rhizoctonia*	Higher shoot and root biomass with *Rhizoctonia*; no difference without	*A. trapezoides, A. rosea*	Stephens et al. 1994d,e; Australia
Wheat with and without take-all disease (*Gaeumannomyces*)	Higher root and shoot biomass with take all; no difference without, after 83 days	*A. trapezoides, A. rosea*	Stephens et al. 1994f; Australia
Subterranean clover	32% shoot, >2x nodule number after 49 days	*A. trapezoids*	Stephens and Davoren 1994; Australia
Maize	65-310% shoot, 52% root, 9-169% total yield	*M. anomala*	Gilot, 1994; Peru
Panicum maximum (Yam)	51-247% shoot, 7-158% root, 67-201% total yield	*M. anomala*	
Oats	3-52% shoot, 10-112% grain,	At least 27 species	Blakemore 1994; Australia
Sorghum	6-27% shoot	At least 27 species	
3 grass species	8-72% shoot, 5-50% root, 1-29% total yield	At least 27 species	
P. maximum, Various grass	7-88% shoot	9 species 10 species	Blakemore 1994; Australia
Mimosa scabrella	43-69% shoot	*Amyntthas* spp.	Kobiyama 1994; Brazil
Beans	3% shoot, 1-9% grain	*Amyntthas* spp.	dos Santos 1995; Brazil
Wheat	6-17 shoot, 3-9% grain	*Amyntthas* spp.	
Tea	135-351% shoot	*P. corethrurus* + 4 species	Giri 1995; India
Tea	12-57% shoot, 29-156% Root, 9-95% total yield	*P. corethrurus*	Giri 1995; India
Wheat with and without take-all and *Rhizoctonia* together	higher grain, shoot and root biomass with *A. trapezoides* + or - disease;	*A. trapezoides* *A. rosea*	Stephens and Davoren 1995; Australia
Wood barley seedlings	15% shoot after 37 days	*O. lacteum*	Klebsch et al. 1995; Germany
Maize	4-52% shoot, 55-120% root, 31-40% grain, 2-9% total yield	*P. corethrurus*	Pashanasi et al. 1994, 1996; Charpentier 1996; Peru
Cowpea	11-45% shoot, 22-32% root, 1-19% grain, 4-20% total yield	*P. corethrurus*	

Table 1. Continued

Plant	Earthworm treatment (Percent change in production over control)	Earthworm Taxa involved/used	Reference and Country
Rice	1-188% shoot, 42-146% root, 10-108% grain, 4-187% total yield	*P. corethrurus*	
Subterranean clover, Ryegrass ± *Rhizoctonia*	>shoot and root mass of both plants with *Rhizoctonia*, > mass of ryegrass without	*A. rosea, A. trapezoids*	Stephens and Davoren 1996; Australia
Wheat, Barley, Faba beans	Increase in wheat and barley in some soils; no increase in Faba	*A. trapezoides, A. rosea*	Doube et al. 1996; Australia
Hordelymus europaeus	-29% roots after112 days; no effect on shoot	*A. caliginosa*	Alphei et al. 1996; Germany
Correlation worm mass and barley yields	significant correlation r = 0.88 total plant, r = 0.75 grain	*A. rosea, A. trapezoides*	Doube and Schmidt 1997; Australia
Peanuts, Rice, Maize	3-214% shoot, 7-111% root, 19-201% grain, 6-67% total yield	*P. corethrurus*, *H. africanus* *M. anomala*, *C. zielae* *S. porifera*	Derouard et al. 1997; Ivory Coast
Maize	1-24% shoot, 6-32% grain,	*M. anomala*	Gilot 1996; Ivory Coast
Brachiaria decumbens	9-50% shoot, 20-88% root, 1-53% total yield	*P. corethrurus*	Patron 1998; Mexico
Rice	20-54%shoot, 7-55%root, 95-230% grain, 33-70% total yield	*D. willsi*	Senapati et al. (Unpubl.); India
Maize	14-76% shoot, 20% total yield	At least two worm species	Brussard et al. (Unpubl.); Cameroon
Bean	8-150% shoot, 36% root, 3-88% total yield	*P. elongate* *P. corethrurus*	Brown et al. (Unpubl.); Mexico
Maize	5-25% shoot, 3-61% root, 3-76% grain, 2-17% total yield	*P. elongate* *P. corethrurus*	Patron et al. (Unpubl.) Mexico
Tea	Shoot biomass (+42-88%) Root biomass (+20-108%) Leaves number (+73-152%)	*P. corethrurus*	Giri 2006; India

Source: Brown et. al. 1999, G.G. Brown (Personal Communicationto Giri), Giri 1995, Giri, 2006

There had been significant increase in shoot length, number of lateral buds and number of leaves. There was also increase of root length and the number of rooting points. Length of the root was highest in the control set while in the various input sets the root length decreased but the number and biomass of the feeder roots increased. Giri (2006) concluded that, due to less nutrient availability in the control set the root length increased for search of food while in the other sets i.e. with different quality of organic matter due to ready availability of nutrients, the search of food decreased and rooting area increased with growth of more number of feeder root for maximum absorption of the nutrient, hence decreased length of the root and increase in the number of rooting points. Shoot and root morphology changes with placement of organic matter, availability of nutrient and distance from the nutrient source.

The inoculation of earthworm biomass of 127 g m^{-2} of *Pontoscolex corethrurus* in pot experiments showed positive increase in the shoot and root biomass and the total plant biomass. The growth of tea cuttings increased rapidly and the time period from initial planting of the tea cuttings in nursery bags to the planting stage in field, was shortened by around 6 to 7 months (it takes 14 to 16 months in the tea nursery). This was considered an extra financial gain to the tea planters in terms of time and money. Soil biological management reduces input costs by enhancing the resource use efficiency.

Table 2: Nutrient composition of high quality organic matter Humigold (Giri 2006)

1.	pH :	7.6
2.	Electrical conductivity (mS cm^{-1})	3800
3.	Carbon content (g %)	8.55
4.	Nitrogen content (g %)	0.67
5.	Phosphorus content (P_2O_5) (%)	2.36
6.	Potassium content (K_2O)	0.65
7.	Carbon: Nitrogen ratio	12.8

As most of the tea gardens have been established in areas previously under natural forests, a comparison of forests and tea garden ecosystems reveals the impacts on tea cultivation on ecosystem structure and functions (Table 3). Compared to a total of 13 earthworm species sampled in forests, 7 species were sampled from tea gardens. *Pontoscolex corethrurus*, *Megascolex insignis* and *Notoscolex spp.* were found in the tea estate, *Pontoscolex corethrurus* being the dominant species (contributing >80% of total earthworm biomass).

Table 3. Comparison of earthworm resource between the Murugalli Reserve Forest and Lower Sheikalmudi Tea Estate (S. Giri, unpublished)

Species	Ecological Category	Reserve Forest	Tea Estate
Amynthas alexandri (Beddard)	Epi-anecic	√	√
Drawida spp.	Endogeic	√	x
Drawida spp.	Endogeic	√	x
Megascolex elongus	Endogeic	√	x
Megascolex filisetae	Anecic	√	x
Megascolex insignis	Anecic	x	√
Megascolex polytheca zonatus	Anecic-Endogeic	√	x
Megascolex spp.	Endogeic	√	√
Megascolex spp. (polytheca group)	Epi-anecic	√	√
Megascolex spp.	Endogeic	√	x
Metaphire houlleti (Perrier)	Epi-anecic	√	x
Moniligaster horstii (Gates)	Epigeic	√	x
Notoscolex spp.	Endogeic	x	√
Pontoscolex corethrurus	Endogeic	x	√
Travoscolides duodecimalis	Endo-anecic	√	x
Travoscolides spp.	Anecic	√	x
Unidentified species	Endogeic	x	√
Total number of species		13	07

Soil Characteristics

Soil physical, chemical and biological properties deteriorate following conversion of natural forests to tea gardens employing the present technology. Chemical fertilizers viz., ammonium-sulphate, ammonium-nitrate and anhydrous ammonia are commonly used in tea plantations in huge quantities, leading to lowering of soil pH, base saturation, organic carbon and cation exchange capacity. soil pH in some gardens is reported to be 3.8 compared to 4.5 to 5.6 required for optimal performance of tea. Acidic soil is low in calcium content and very rich in sesquioxides of aluminium and iron resulting in metal toxicity. Tea being a cash crop with continuous removal of green leaves, the system remains always under high input of fertilizers and pesticides (Table 4)

Senapati et al. (2002) concluded that continued use of inorganic fertilizers and discontinuance of old method of tea leaf pruning matter burial and organic manure application over the years caused increase in soil acidity by 8%, reduction in water holding capacity by 9%, cation exchange capacity by 32% and organic matter by 33% in tea gardens (Table 4). Application of fertilizers and pesticides together with human induced trampling of the soil during tea harvesting reduced beneficial soil macro- fauna abundance and increased abundance of termite pests (Tables 5 and 6).

The ratio of termite to earthworm populations calculated for several sites showed that this ratio can be used as an indicator of soil degradation. In high inorganic fertilizer input system like tea, epigeic and anecic species are almost eliminated and only deep burrowing endogeic worms are present.

Table 4. Comparison of soil properties between the Murugalli Reserve Forest and Lower Sheikalmudi Tea Estate (S. Giri, unpublished data)

Parameters	Reserve Forest	Tea Estate	Percent change in tea estate over reserve forest
PHYSICAL			
(i) Coarse sand (%)	38.55 ± 1.41	55.46 ± 1.41	+43.87
(ii) Fine Sand (%)	21.69 ± 2.20	16.70 ± 2.20	- 23.01
(iii) Silt (%)	23.49 ± 0.79	16.93 ± 0.79	- 27.93
(iv) Clay (%)	16.27 ± 1.73	10.91 ± 1.73	- 32.94
(v) Water Holding Capacity (%)	56.20 ± 0.87	51.10 ± 1.35	- 9.07
CHEMICAL			
Soil pH 4.81 ± 0.04	4.39 ± 0.07	- 8.73	
Electrical Conductivity (mS)	0.10 ± 0.01	0.16 ± 0.01	+59.79
Cation Exchange Capacity (meq%)	5.92 ± 0.75	4.01 ± 0.24	-32.26
Oxidisable Organic Matter (g%)	3.80 ± 0.38	2.56 ± 0.12	- 32.56
Organic Carbon (g%)	2.21 ± 0.30	1.49 ± 0.11	- 32.61

Table 5. Comparison of density (numbers m^{-2}) and biomass (fresh weight, g m^{-2}) of soil biota in the Murugalli Reserve Forest and Lower Sheikalmudi Tea Estate (S. Giri, unpublished data)

Parameters		Reserve Forest	Tea Estate	Percent change in tea estate over reserve forest
Termite	Density	180.40 ± 112.20	73.60 ± 52.20	- 59.20
	Biomass	0.67 ± 0.43	0.45 ± 0.29	- 33.28
Total Arthropod	Density	289.20 ± 132.80	129.60 ± 49.77	- 55.19
	Biomass	8.71 ± 5.22	1.83 ± 0.92	- 79.03
Earthworm	Density	195.20 ± 38.10	88.00 ± 20.31	- 54.92
	Biomass	198.20 ± 52.53	24.41 ± 14.46	- 87.68
Molluscs	Density	1.60 ± 1.68	0.00 ± 0.00	- 100.00
	Biomass	0.07 ± 0.07	0.00 ± 0.00	- 100.00
Total Macro-invertebrates	Density	486.00 ± 156.00	217.60 ± 49.39	- 55.23
	Biomass	207.00 ± 53.83	26.24 ± 14.37	- 87.32

Table 6. Comparison of biomass ratios of different groups of soil biota in the Murugalli Reserve Forest and Lower Sheikalmudi Tea Estate (S. Giri, unpublished data)

Groups	Reserve Frest	Tea Estate	Percent Change in Tea Estate over Reserve Forest
Termite/Earthworm ratio	0.003	0.018	-
Arthropod/Earthworm ratio	0.043	0.075	-
Macro-fauna/Earthworm ratio	1.044	1.075	-
Total microbial biomass (g m^{-2})	746.00 ±25.60	395.10±8.98	-47.04
Litter weight (g m^{-2})	4320.00±343.90	1712.00±93.35	-60.37
Humus weight (g m^{-2})	1424.00±136.50	1302.00±268.70	-8.57

Senapati et al. (1994, 1999 and 2002) have developed “In-soil Earthworm technology” for tropical tea based Agro ecosystems. This research on “Restoration of degraded soil in intensive tea plantation in south India” was carried out in three phases: (i) Comparison of Reserve Forests and tea gardens, as discussed earlier, (ii) Evaluation of the impact of application of inorganic fertilizer and organic manure on soil physico-chemical and biological properties and tea production, (iii) Evaluation of impact of direct and indirect management of earthworms (direct management – massive inoculation of earthworms; indirect management: alterations in environmental conditions such that existing earthworm population is favoured) on soil system and tea production in comparison with the existing tea cultivation technologies.

In high inorganic fertilizer input system of tea garden, epigeic and anecic earthworm species were eliminated and only the deep burrowing endogeic species were present. It was found that the termite to earthworm biomass ratio in the tea gardens can be used as an indicator of soil degrasdation.

Impact of Input Operational Management

A large scale input operational experiment was carried out on large plots of one hectare each in Caroline tea estate (Caroline group in Nilgiris hill range) of Parry Agro Industries Ltd. The details of experimental design involved choosing four blocks of one hectare each facing east-west direction. Each block contained 4400 tea bushes of Assam Jat variety and the blocks were demarcated with stone pillars. A transitional zone of 4 bush line was left between each experimental plot.

“Block A” was used as control block where zero dose of inorganic fertilizer (I0) and zero dose of organic manure (O_0) was applied; (ii) “Block B”, was maintained with conventional management practice of 100% inorganic fertilizer application dose (I_{100}), (iii) “Block C”, was maintained with 100% organic manure application dose(O_{100}) and (iv) “Block D” were maintained with 50% inorganic fertilizer and 50% organic manure application dose ($I_{50}O_{50}$). Organic manure doses were worked out based on NPK fertilizer equivalence, with full doze of inorganic fertilizer taken as 300 kg N ha^{-1} as practiced by Parry Agro Industries Ltd. High quality organic manure used in the experiment was a commercially available brand called “Humigold” (Senapati et al. 1994). An enhancement of green tea leaf production by 18% in Block C with 100% organic manure and zero inorganic dose (I_0O_{100}) and by 40% in Block D with 50% organic manure and 50% inorganic fertilizer dose ($I_{50}O_{50}$) over 100% inorganically fertilizer managed Block B ($I_{100}O_0$) was noted. There was 16% expenditure saving in block D and 32% saving in block C over Block B. Possible mechanism of actions for enhancement of production and expenditure saving were attributed to improvement in beneficial macro- fauna abundance and improvement of other soil parameters which enhanced soil fertility (Table 7).

Impact of Management Alternatives of In-soil Earthworm Technologies

There are two management alternatives of in-soil earthworm technologies: (I) the Indirect in-soil earthworm technology includes promotion of suitable conditions for the activities of already existing popu-

Table 7. Tea production and cost benefit analysis of different techniques used in different experimental blocks (Senapati et al. 1994)

Parameters	Experimental Blocks			
	Block A (I_0O_0)	Block B($I_{100}O_0$)	Block C (I_0O_{100})	Block D ($I_{50}O_{50}$)
Total green leaf production (kg live weight, ha^{-1} yr^{-1})	13968	15858	18735	22163
Percentage increase over conventional plot	-11.92	-	+18.14	+39.80
Made Tea Production (kg ha^{-1} yr^{-1})	3212.64	3647.34	4309.05	5097.49
Income (US$, ha^{-1})	3533.90	4012.07	4739.96	5607.24
Investment towards chemicals and manures (US$ ha^{-1})	10.8	200.5	130.8	165.7
Investment towards manpower (US$ ha^{-1})	20.0	30.0	27.0	165.7
Total Investment (US$ ha^{-1})	30.8	230.5	157.8	194.2
Percentage change in expenditure over conventional plot	-86.6	-	-31.5	-15.8
Intermediate Profit * (US$ ha^{-1})	3503.11	3781.57	4582.16	5413.04
Percentage difference over conventional	-7.36	-	+21.17	+43.14

*: Does not include other company costs (salaries of administrative staff, offices, machineries, land tenure etc.

lations through the manipulation of plant communities and/or organic inputs and (ii) Direct in-soil earthworm technology includes by the direct massive inoculation of suitable population of earthworm. The synchrony hypothesis proposed by TSBF programme along with other themes like soil organic matter, soil water, soil fauna and resource integration was followed in the tea garden input operational experiment. In the experiment a technique was developed to stimulate growth of tea plants and enhance soil quality. This technique uses a combination of mechanical intervention (digging trenches in contour lines), input of organic matter of different qualities in a specific spatiotemporal design and the inoculation of earthworms produced locally using a special technology (Giri 2005; Senapati et al. 2002).

The input operational experiment was carried out in tea estate of Parry Agro Industries Limited. Both direct and indirect technology methods were adopted in the experiment. Five blocks of one hectare each were selected facing east-west direction. Each block contained 5500 tea bushes of Assam Jat variety planted in 1926. The plants were pruned during May 1994. Each blocks were demarcated with stone pillars and a transitional zone of 4 bush line was left in between the two experimental blocks. The five blocks were (i) "BLOCK A" or Control Block was maintained with conventional management practice by Parry Agro Industries Ltd. i.e. the plot received only 100% inorganic fertilizer dose on the soil surface, (ii) in "BLOCK B" contour trenches (1.8 m long, 30 cm broad, 45 cm deep) were made in a lock and spill arrangement between the tea bushes (during pruned period), (iii) in "BLOCK C", contour trenches were made and earthworms of specific weight were inoculated in trenches, (iv) in "BLOCK D" contour trenches were made and tea pruning material, a low quality organic matter of specific weight were buried in trenches and (v) in "BLOCK E" contour trenches were made and both tea pruning material burial and earthworm inoculation was in trenches. Earthworms were reproduced by vermi-composting in large covered beds and inoculated in the experimental fields. The block received a surface application of 50% inorganic fertilizer dose and 50% organic manure (Humigold). Green leaf production and cost benefit analysis was done to assess the effect of the direct and indirect input operation experiment on the tea production (Table 8).

The work is site specific and the details of the synchro-nization hypothesis have not been published by the authors. This technology has been patented (entitled "Fertilization Bio-Organique dans les Palntations Arborees" (FBO) ref. PCT/FR 97/01363). Reviewing the Indian work on macro-fauna, especially earthworms, Dash and Dash (2008) concluded that a number of species (Table 9) can be mass cultured and introduced for improving soil health in degraded ecosystems in India. A field earthworm inoculation protocol based on crop life cycle and soil conditions is to be developed. India has diverse ecological situations

Table 8. Tea production and cost benefit analysis of different techniques used in different experimental blocks (Senapati et al. 2002)

Parameters	Conventional Method (Block A)	Trenches Alone (Block B)	Trenches + Earthworm Inoculation (Block C)	Trenches + Tea Pruning Burial (Block D)	Trenches + Earthworm Inoculation+ Tea Pruning Burial (Block E)
Made Tea Production (kg, ha^{-1}, yr^{-1})	2306	3104	8377	3132	8667
Percentage increase over conventional plot	-	+34.6	+263.0	+35.8	+276.0
Income (US$, ha^{-1})	2537	3414	9215	3445	9534
Investment towards chemicals and manures (US$, ha^{-1})	121	162	162	205	205
Investment towards manpower (US$, ha^{-1})	419	573	1541	602	1600
Investment towards trench management[a] (US$, ha^{-1})	-	21[b]	21[b]	21[b]	21[b]
Investment towards earthworm management[a] (US$, ha^{-1})	-	-	114[b]	-	114[b]
Total Investment (US$, ha^{-1})	540	756	1838	828	1940
Intermediate Profit[c] (US$, ha^{-1})	1997	2658	7377	2617	7594
Percentage difference over conventional	-	+33.0	+269.4	+31.0	+280.3

a: Trench management includes only trench making expense; earthworm management includes earthworm culture, harvest, earthworm application and trench filling; b: Costs of earthworm management and trenching are divided by four since this management occurs in every four years interval, c: Does not include other company costs (salaries of administrative staff, offices, machineries, land tenure etc..

and rich in earthworm fauna (Julka and Paliwal 2005), hence it will be rewarding to carry out this type study in other land uses.

Vermicomposting

Earthworms (worms) are now utilized (i) for converting municipal organic waste, agricultural organic waste, canteen waste into manure through vermicomposting and other uses, (ii) for producing vermifeed as protein source for fish and poultry; (iii) for large scale vermiculture for production of worm cast, which are utilized as vermi-manure and for water holding substrate for growth of edible mushrooms, (iv) for raising plant productivity in degraded lands through inoculation of earthworms. All technologies centered around utilization of earthworms are called vermi-technology. The technology mentioned in (iv) have already been discussed and those mentioned in (i), (ii) and (iii) are discussed in this section.

The science of vermicomposting took shape during 20^{th} century and the first vermicomposting plant was started in Holland landing, Ontario, Canada (Appelhof 1980, 1981). Since then the technology has become very popular all over the world with several modifications (Hartenstein et al. 1979, Collier and Livingstone 1981, Dash and Senapati 1980, 1985, Singh 1997, Ndegwa and Thompson 2000, Gaja-lakshmi et al. 2001, Frederickson and Howell 2003, Arancon et al. 2003 a,b,c, Chaudhuri et al. 2003, Pizl 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, Pattanaik and Reddy 2009).

Most of vermicomposting efforts deal with three earthworm species, *Eudrilus eugeniae, Eisenia foetida* and *Perionyx excavatus*. Although *Perionyx excavatus* is a native species and *Eisenia foetida* an exotic that has successfully colonized many ecosystems. *Eudrilus eugeniae* is an exotic species with infrequent distribution in nature but is widely used in Indian laboratories. If this exotic species escapes, it may threaten native species. The exotic species should only be used under controlled conditions in the bioreactors and should not be released to the field (Dash and Dash 2008). Bhadauria and Rama-krishnan (2005) have found many exotic species in North-east and Central Himalaya but their ecological implications have not been fully assessed. The outbreak of foot-and-mouth disease and fungal pathogens in Europe related to earthworm import points to the need of use of the native species in vermicomposting (Hendrix and Bohlen 2002).

As part of a research project on Conservation and Management of Belowground Biodiversity sponsored by TSBF (Indian part), Chandrasekara et al. (2009) compared growth of some annual crops in (1) Control (weeds (250 kg + Rock phosphate (1%) + urea (1kg urea per Mg of weed biomass) + wood ash (5%), (2) Control + Consortia of beneficial microbes (2 species of bacteria + 2 species of fungi and 11 species of actinomycetes showing maximum phenol oxidase and cellulase activity), (3) Control + Microbial inoculation + Earthworms (*Eudrilus eugeniae*, 1500 worms per Mg of substrate), (4). Control + Cow dung slurry and (5) Control + Cow dung slurry + Earthworms (*Eudrilus eugeniae*, 1500 worms per Mg of substrate). The preliminary result indicate that all test crops showed best performance in treatment 3 followed by the treatment 2 indicating the benefits of vermicompost.

Dash (1994, 1999), Mishra, P.C. and Sahu, S.K. of Sambalpur University (1998, 2002- personal communication) have used native species like *Lampito mauritii*, *Drawida sunderghensis, Drawida boluii (*exotic but naturalized now) to convert canteen and other organic wastes into manures in many industrial set-ups in Orissa and West Bengal. The changes in C/N ratio, C/P ratio, concentrations of available N, P and K, phosphatase activity in worm casts, microbial interactions, time for thermal stabilization, life history parameters like growth, cocoon production and some other parameters have been taken as criteria for judging the efficiency of earthworms in the vermicomposting process.(Dash and Dash,2008). Importance to local species in vermicomposting has also been given elsewhere (Dash and Senapati 1980, 1985, Singh 1997, Gajalakshmi et al. 2001, Maity et al. 2008, Dash and Dash 2008, Reinecke and Viljoen 1990).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 wastes from food processing plants, sugar mills, paper mills and kitchen waste and for field inoculation as vermifeed material. Table 10 gives comparative account of the vermicultural characteristics of some Indian earthworms including, *Perionyx excavatus*, *Eisenia foetida* (= *fetida*) and the exotic, *Eudrilus eugeniae.*

Analysis of the changes in the concentration of major nutrients of vermicompost of municipal organic solid waste processed by *Eudrilus eugeniae, Eisenia foetida* and *Perionyx excavatus* showed that the bulk mass of the waste was reduced up to 65, 55 and 40%, respectively, by the three species. However, the body growth and reproductive fitness (cocoon production) was significantly higher in *Perionyx excavatus* compared to the other two species. The pH, conductivity and concentrations of major nutrients in the vermicompost gradually increased while the organic carbon, C/N ratio and C/P ratio decreased as the composting process progressed. The vermicompost of the earthworm species showed higher concentration of nutrients than that of compost and the substrate (Pattnaik and Reddy 2009). Recently Chaudhuri and Bhattacharjee (2009) have compared the vermiculture characteristics of 7 species of earthworms found in Rubber plantations in Tripura and suggest that *Pontoscolex corethrurus, the dominant endogeic-anecic species* has a better reproductive fitness over other species (Table 11) and this species can be used in vermicomposting. Since *Pontoscolex corethrurus* is endogeic and predominantly geophagus, its potentiality for vermicomposting of different organic substrates requires detailed study.

There is a need of research to standardize the bioreactor conditions, type and quality of organic waste-substrate and to develop a protocol for use of vermicompost in field. Research on screening of potentiality of Indian earthworm species as cited above for vermitechnology purpose should be considered a thrust area for research funding. Selection of earthworm species should emphasize on the rate of biomass consumption, and worm growth, reproductive potential and adaptability of the species. In general worms should be capable of performing 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). Tables 9 and 10 list the species suitable for vermicomposting.

Vermi-Protein

Earthworm tissue contains more than 50% proteins on dry weight basis (Dash et al. 1977), with many essential amino acids available in their body tissue. In an experiment earthworm dry tissue was fed to Japanese quails and chicks 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 0.024 and 0.025 respectively for fish meal and earthworm meal ration. (Das and Dash 1989, 1990).

Table 9. Earthworm species tolerating high concentration of organic matter and suitable for vermitechnology *

Native species	Exotic species
Perionyx excavatus	*Eudrilus eugeniae*
Perionyx sansibaricus	*Eisenia fetida* **
Perionyx ceyalensis	*Drawida bolui* **
Metaphire posthuma	
Moniligaster perrieri	
Megascolex insignis	*Metaphire posthuma* **
Drawida robusta	*Polypheretima elongate* **
Drawida willsi	
Drawida nepalensis	
Lampito mauritii	
Megascolex cochinensis	
Hoplochaetella suctoria	
Hoplochaetella khandalaensis	
Octochaetona surensis	
Lennogaser dashi	

* Based on Julka (personal communication)
** adapted to Indian habitats

This type of study on different earthworm species can provide useful data for possibility of commercial use of earthworms as poultry and fish feed material.

Vermi-cast Supplementation for Mushroom Growth

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). Earthworm casts of different species can be compared to find out the most suitable substrate dressing material for edible mushroom growth.

CONCLUSIONS

Several studies provide evidence that earthworms can be used as a tool to raise productivity of agroecosystems and to recover ecosystem functions in degraded tropical lands. However, practical examples of demonstrating the potential of earthworm based are limited. Comprehensive research and development programmes are needed for enhancement of potential benefits from soil fauna in terms of parallel improvements in productivity, profitability and environmental functions of terrestrial ecosystems.

Table 10. Vermiculture characteristics of some Indian earthworms suitable for vermicomposting (Dash and Dash 2008)

Species	Soil temperature for maximum growth	Age for cocoon production (weeks)	Upper limit of temperature ^{o} C	Vermi-stablization time (weeks)	Number of young per cocoon	Incubation period (weeks)	Averge size (live wt, 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)

Family

(Chaudhuri and Bhattacharjee 2009)

Species *papillifer* *comillahnus* *chittagongensis*

*Biovolume = $\pi r^2 l$, r = radius, l = length, t

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Table 11. Ecological category, feeding habit, and habitat and size relationship of eight species of earthworms of rubber plantation in Tripura (Chaudhuri and Bhattacharjee 2009)

Species	Family	Size (mm)	Biovolume* mm^3	Color	Feeding habit	Distribution pattern	Ecological category	Soil Characters			
								Temp. °C	Moisture %	pH	O. M. %
Pontoscolex corethrurus	Glossoscolecidae	L=72-100 B=4-5	1367.08	Lightly pigmented	Geophagous	Exotic peregrine	Topsoil endogeic	19-32	10-29	4.5-4.8	1.7-2.4
Drawida Papillifer papillifer	Moniligastridae	L=45-90 B=3-4	649.09	Deeply pigmented	Phytogeophagous	Endemic	Epianecic	22-32	10-29	4.5-4.7	1.6-2.4
Drawida assamensis	Moniligastridae	L=60-80 B=4-5	1112.74	Lightly pigmented	Phytogeophagous	Endemic	Topsoil endogeic	21-31	10-29	4.4-5.2	1.5-2.0
Metaphire houlleti	Megascolecidae	L=100-160 B=3-6	2551.25	Deeply pigmented dorsally	Phytogeophagous	Endemic peregrine	Epianecic	21-28	14-20	4.4-5.2	1.6-2.0
Eutyphoeus comillahnus	Octochaetidae	L=70-135 B=2-4	724.16	Lightly pigmented	Geophagous	Endemic	Mesohumic endogeic	21-27	17-18	4.5-4.6	1.7-2.0
Dichogaster affinis	Octochaetidae	L=35-42 B=1-2	68	Moderately pigmented	Phytophagous	Exotic peregrine	Epigeic	21-28	17-21	4.8-5.2	1.8-2.0
Octochaetona beatrix	Octochaetidae	L=60-120 B=4-5	635.85	Lightly pigmented	Geophagous	Endemic peregrine	Subsoil endogeic	24-28	11.5-14	4.7-4.8	1.6-2.0
Lennogaster chittagongensis	Octochaetidae	L=40-50 B=1.5-2.5	565.2	Lightly pigmented	Phytogeophagous	Endemic peregrine	Topsoil endogeic	24-30	16-18	4.7-4.8	1.5-2.0

*Biovolume = $\pi r^2 l$, r = radius, l = length, they suggest that *Pontoscolex corethrurus* can be used in vermicomposting (?); O.M. = organic matter