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Impact of five different species of bamboo plantations on earthworm communities in West Tripura (India)

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Abstract

A field study undertaken in 5 different species of bamboo plantations in West Tripura revealed presence of 18 species of earthworms belonging to 4 different families *viz* Megascolecidae [*Metaphire houlleti* (Perrier), *Kanchuria* sp1, *Lampito mauritii* Kinberg, *Amynthus alexandri* (Beddard), *Perionyx excavatus* Perrier, *Metaphire posthuma* (Vaillant)], Octochaetidae [*Eutyphoeus gigas* Stephenson, *Eutyphoeus comillahnus* Michaelsen, *Eutyphoeus orientalis* (Beddard), *Dichogaster bolaui* Michaelsen, *Lennogaster chittagongensis* (Stephenson), *Lennogaster yeicus* (Stephenson), *Eutyphoeus turaensis* Stephenson and *Octochaetona beatrix* (Beddard)], Moniligastridae [*Drawida assamensis* Gates, *Drawida nepalensis* Michaelsen and *Drawida papillifer papillifer* (Stephenson) and Glossoscolecidae (*Pontoscolex corethrurus* Muller). One species *E. comillahnus* is restricted only to Tripura of India. Bamboo plantations were mostly dominated by endogeic (geophagous) species. Among the plantations *B. polymorpha* had the highest density (175 ind./m^2) and biomass (75 g/m^2) of the earthworms, whereas the highest earthworm diversity (Ĥ 1.67) was found in *B. cacharensis* plantation.

Keywords: Bamboo Plantations, Communities, Earthworm, India, West Tripura

Introduction

Bamboos (Poaceae), native to South-East Asia are the most important socio-economic resource in northeast India. Besides fulfilling the diverse needs of rural livelihoods in northeast India, bamboos act as potential site of carbon sink (Nath and Das 2012). According to Tu *et al.* (2013) bamboo plantation increases soil microbial and enzyme activities, thereby enriching soil fertility. In India, bamboo plantation occupies 12.8% of the total forest areas of our country comprising 22 genera and 136 species (Thokchom and Yadava, 2017). Since 1999 about 11,400 ha areas of bamboo plantations have been raised by the Forest Department of Tripura (Gupta, 2008). Due to its high commercial viability for manufacturing durable goods, like building materials for house, furniture etc., local people have cultivated various species of bamboos in their homestead and plain lands which face various degrees of anthropogenic managements. According to Thokchom and Yadava (2017) appropriately managed and regularly harvested bamboos can sequester more carbon than bamboos in natural state. Total litter production from bamboos varies from 868 kg to 1125 kg ha^{-1}year^{-1}, with a mean of 1032 kg ha^{-1} year^{-1} (Nath and Das, 2011a). As bamboo leaf litter form an effective substrate for growth and reproduction in earthworms (Chaudhuri and Bhattacharjee, 2002), and since bamboo plants having canopy cover and bamboo leaf litter with their mulching effects are found in abundance over the plantation floor throughout the year, it is reasonable to predict rich earthworm density and biomass under bamboo plantations, compared to other monoculture plantations in northeast India.

The role of earthworms in decomposition process, nutrient cycling and on building and maintenance of soil structures has been well documented (Edwards and Bohlen, 1996). On the basis of feeding habit and burrowing-cum-casting activities, earthworms belong

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to three basic ecological categories i.e., epigeic, endogeic and anecic (Edwards and Bohlen, 1996). Epigeic worms are litter feeders, non-burrowing surface living species producing casts over surface. Geophagous endogeic species form horizontal, complicated burrows and produce casts generally below the ground. Anecic earthworms are phytogeophagous species producing vertical burrows and casting at the soil surface. Zhang *et al.,* (2013) advocated that earthworms accelerate carbon activation and facilitate carbon sequestration generating an earthworm mediated 'carbon trap' in their burrows. Thus soil carbon and earthworms are important components in sustainable tropical agro-ecosystem, the typical example of which is bamboo plantation. According to Gonzalez *et al.* (1996) and Tien *et al.* (2000) tree plantations may influence earthworm abundance by altering the physico-chemical properties such as temperature, moisture regime, pH, organic matter content and litter inputs in soils. Sarlo (2006) advocated that individual tree species rather than monoculture or polyculture, providing a better microclimate, favoured earthworm biomass and that the biomass of earthworms was significantly correlated with the canopy cover.

Although both bamboo plants and earthworms have possible role in carbon sequestration and bamboo leaf litter forms an effective food substrate for growth and reproduction in earthworms (Chaudhuri and Bhattacharjee, 2002), reports are scanty on individual plant species effects on the earthworm communities under different species of bamboo plantations. In the present communication, we have investigated the community characteristics of earthworms in the soils under different species of bamboo plantations such as *Bambusa cacharensis* (local name *Bom*), *Bambusa polymorpha* (*Bari/Paura*), *Bambusa balcooa* (*Barak*), *Bambusa bambos* (*Katabarak*) and *Melocanna baccifera* (*Muli*) in West Tripura.

Bambusa cacharensis plantations are endemic to Assam (Majumder 1983; Barooah and Barthakur, 2003). *Melocanna baccifera* plantations are believed to be native to the Chittagong hill tracks of Bangladesh (Mclure, 1966; Prasad, 1948). Whereas *Bambusa polymorpha* is a large dense clumping tropical bamboo native to Myanmar, Thailand and Bangladesh, *Bambusa balcooa* is indigenous to northeast India including the Eastern Himalayas and Nepal where it is frequently cultivated. *Bambusa polymorpha* and *Bambusa balcooa* plantations grow well in plain residential areas, mostly in the river banks where they are used as embankments to reduce soil erosion. Due to comparatively high commercial value they face better management practices (anthropogenic interference) such as annual harvesting of old culms to maintain vigor of the plants. *Bambusa bambos* plantation, also known as giant thorny bamboo or Indian thorny bamboo, is also a tropical bamboo species native to Southeast Asia. In all these species of bamboos thirty to fifty calms of same species aggregate to form one bamboo clump except in *M. baccifera* where the upright plants had uniform and closely arranged distribution without clump formation.

Material and Methods

The studies were conducted from May 2013 to September 2015 under 5 different species of mature bamboo plantations in West Tripura (22˚5˚-24˚32˚N and 90˚20˚ E). Tripura having an area of 10,491 sq km is almost encircled by Bangladesh except in the north-east, where it meets the neighboring states of Assam and Mizoram. The year is divisible into four seasons namely summer (March-May), monsoon (June-September), short autumn (October) and winter (November-February). The climates of the study sites are sub-tropical, warm and humid with average rainfall of 2000 mm. During the study period average maximum and minimum temperatures were 30˚C and 19˚C respectively. The survey was conducted under locally available mature bamboo plantations belonging to 5 different species viz. *B. cacharensis* (BC), *B. polymorpha* (BP), *B. balcooa* (BL), *B. bambos* (BB) and *M. baccifera* (MB) at 15 localities (3 replica for each species) of Sadar subdivision of West-Tripura. The distance between the sites ranged from 10 to 30 km. Whereas BP and BL plantations were situated on river banks, the other plantations (BC, BB, MB) were on undulating uplands (locally called '*tilla*') with well drained soils. The texture of the soil in BP and BL plantations was clay loam due to relatively higher proportion of silt (26.4% and 30.7% respectively) compared to rest of the plantations where the soil texture was sandy clay loam with relatively less proportion of silt (BC-16.4%, MB-11.5% and BB-10.8%). Bamboo litter fell throughout the year over the plantation floor which seemed to retain moisture in the soil under the bamboo clumps. A good number of weeds and shrubs viz., *Mallotus philippensis* (Euphorbiaceae), *Eupatorium odoratum* (Asteraceae), *Grewia nervosa* (Malvaceae), *Olax acuminata* (Olacaceae), *Streblus asper* (Moreceae), *Calamus rotang* (Arecaceae), *Ziziphus rugosa* (Rhamnaceae), *Chassalia curviflora* (Rubiaceae) etc., grew under the bamboo plantations. The soils of the bamboo plantations in general, were acidic, sandy clay loam to clay loam in texture with total soil nitrogen (N) 0.18-0.23%, available soil P 25-48 mg Kg^{-1} and exchangeable K 54-64 mg kg^{-1} (Nath and Das 2011 a,b).

Experimental Design

Earthworms were collected by TBSF monolith (25cm × 25cm × 40cm) digging and hand sorting method (Anderson and Ingram, 1993). This method works well in tropical soils where earthworm communities are largely dominated by endogeic species. At least eight to ten clumps separated by 10 meters were randomly selected for sampling in each site (>1 ha area). A composite sample comprising five soil monoliths was taken around the clumps (BC, BP, BL, and BB) and at four corners and centre of 10M × 10M plot in MB. A total of 140 (±2) samples were taken from each sampling site. Earthworms were counted, rinsed in water soaked in cotton cloths and weighted (with gut contents) on electronic balance under field condition. Some clitellate earthworms (8-10) were preserved in 10% formalin (for identification) and others were released into soil ecosystem for biodiversity conservation. Results were expressed in terms of biomass (fresh weight, g m^{-2}) and population density (ind.m^{-2}). Earthworm species were identified following keys adopted by Gates (1972) and Julka (1988). Casting activities were quantified by collecting fresh earthworm casts in 1 m^2 quadrates from four species bamboo plantations except those in BL where casts were not well detected due to severe human activities almost throughout the year. The casts thus collected were dried at room temperature for one month and the dry weights of the casts were noted for each plantation type. Bamboo leaf litter were collected and weighted for estimating the litter production under different plantation types.

Data Analysis

The data from all the species collected during the study periods were applied to determine the relative abundance, frequency, species evenness (Dash and Dash, 2009), dominance (Engelmann, 1973), index of general diversity (Shannon and Wiener, 1963), index of dominance (Simpson, 1949) and species richness index (Menhinick, 1964). Variations in physico-chemical properties of soil and some biological and ecological parameters like earthworm density, biomass, casts and litter production among the five plantation types were tested using one way ANOVA at 5% level of significance (Zar, 1999). Where significant factors were evident, Tukey's post-hoc test (Tukey, 1953) was applied to examine which particular means were significant at 5% level. Difference among the species indices were tested non-parametrically by using Kruskal-Wallis analysis of variance (Kruskal and Wallis, 1952). Similarities of earthworm species composition in 5 different species of bamboos were identified using single link cluster analysis based on Bray-Curtis similarity (MC Aleece, 1998).

Soil and Leaf Litter Analysis

Soil samples were collected from a depth of 0-15 cm in the location of maximum earthworm activities (as indicated by the presence of casts) by scraping the wall of the sampled quadrates with a metal shovel. Composite soil samples comprising of 5 sub-samples were prepared for physico-chemical analysis. Collected soil samples were air-dried, crushed with mortar-pestle and passed through 2 mm mesh sieves. Sieved soil samples were analyzed for their pH (1:25 dilution method), oxidizable organic matter content (Walkley and Black, 1934) and soil texture (Daji, 1996). Soil temperature (soil thermometer) and soil moisture (gravimetric wet weight method) were recorded at each sampling point.

Chemical analysis of different species of bamboo leaf litter such as sugar (Dubois *et al.,* 1951), lignin (Dence, 1992; Chang *et al.,* 2008), polyphenols (Gantha *et al.,* 2007), flavonoids (Kalim *et al.,* 2010) and protein (Braford, 1976; Ni *et al.,* 1996) were determined in the CSIR laboratories of Indian Institute of Chemical Biology, Jadavpur, Kolkata.

Results and Discussion

Earthworm diversity is influenced by the physico-chemical characteristics of soil, climate and organic resources of the locality, as well as, its history of land use and soil disturbances.

Habitat Characteristics

Soil physico-chemical properties such as pH, temperature, moisture, organic matter, bulk density, water holding capacity, cast production etc. are given in Table 1. Significantly ($P<0.01$) highest and lowest pH were found in soils of BL and BP. Soil moisture contents were highest and lowest ($P<0.01$) in BL and BB respectively. Significantly highest and lowest ($P<0.01$) organic matter contents were recorded in MB and BB. The soils of MB plantation had significantly higher ($P<0.01$) temperature than those of other plantations due to presence of significantly less amount ($P<0.01$) of leaf litter deposits in it compared to other plantations. There were significant differences ($P<0.01$) in litter productions among different plantations (Table 1). Over ground leaf litter production in BP was significantly higher ($P<0.01$) than that of MB and was at par ($P>0.01$) with other plantations. In fact, litter forms the food base of earthworms and conserves soil moisture favorable for earthworm distribution. The chemical composition of leaf litter of different bamboo species is given in Table 2. In bamboo leaf litter, highest and lowest polyphenol contents were found in BL and BB, highest and lowest sugar contents in BB and BL and lowest and highest protein contents were found in BP and BL.

Earthworm Species Composition

A total of 18 species of earthworms belonging to four different families viz. Megascolecidae [*Metaphire houlleti* (Perrier), *Kanchuria* sp1, *Lampito mauritii* Kinberg, *Amynthus alexandri* (Beddard), *Perionyx excavatus* Perrier, *Metaphire posthuma* (Vaillant)], Octochaetidae [*Eutyphoeus gigas* Stephenson, *Eutyphoeus comillahnus* Michaelsen, *Eutyphoeus orientalis* (Beddard), *Dichogaster bolaui* Michaelsen, *Lennogaster chittagongensis* (Stephenson), *Lennogaster yeicus* (Stephenson), *Eutyphoeus gammiei* (Beddard) and *Octochaetona beatrix* (Beddard)], Moniligastridae [*Drawida assamensis* Gates, *Drawida nepalensis* Michaelsen and *Drawida papillifer papillifer* (Stephenson) and Glossoscolecidae (*Pontoscolex corethrurus* Muller) were found in general among different species of bamboo plantations of West Tripura (Figure 1, Table 3). Number of earthworm species was highest in the BP (16 species) and lowest number of 10 species each for BC and MB (Table 1). BB and BL had 11 and 12 earthworm species respectively. Among 18 earthworm species, 7 earthworm species *viz. M. houlleti*, *P. corethrurus*, *D. assamensis*, *D. papillifer papillifer*, *E. comillahnus*, *O. beatrix* and *Kanchuria* sp1 were common to all the studied bamboo plantations. Restricted distributions of earthworm species were shown by *E. orientalis* (BP, MB), *L. yeicus* (BC, BP), *L. chittagongensis* (BP, BB), *D. nepalensis* (BP), *E. gammiei* (BP), *M. posthuma* (BL) and *P. excavatus* (BP). Thus *P. excavatus*, *M. posthuma*, *E. gammiei* and *D. nepalensis* with relative abundance 0.39%, 2.07%, 0.93% and 0.26% respectively may be considered as rare species of bamboo plantation (Table 3).

Native vs. Exotic Species

Out of 18 earthworm species 5 species were exotic (*M. houleiti*, *A. alexandri*, *M. posthuma*, *D. bolaui* and *P. corethrurus*) and the rest were native to the Indian sub-continent. Among the native species *E. comillahnus*, had restricted distribution only in Tripura of India. Thus this species may be considered an endemic to northeast India. *Kanchuria* sp1 is also a new species (Julka personal communication, 2015) from Tripura. Exotic earthworm species were distributed to all the studied plantations with their highest number (5 out of 12 species) in BL with highest anthropogenic disturbances and lowest number (2 out of 10 species) in the BC and MB with lowest anthropogenic disturbances (Table 1). Occurrence of greater number of native species than exotics in the soils of Tripura indicates that the region belongs to biodiversity hotspot zone where the native species co-exist with the exotics which is quite in contrast to tropical countries like Peru, Brazil and Mexico where native species have largely been replaced by exotics (Fragoso *et al.*, 1999).

Table 1. Ecological and biological parameters in relation to earthworm distribution in different bamboo plantations of West-Tripura

parameter	Mean±SE(Total n = 700)						
	***B.cacharensis* (BC)(n= 140)**	***B.polymorpa* (BP) (n= 142)**	***M. baccifera* (MB)(n= 140)**	***B. balcooa* (BL)(n= 138)**	***B. bambos* (BB) (n= 140)**	**F /H value**	**P Value**
Soil texture	Sandy clay loam	Clay loam	Sandy clay loam	Clay loam	Sandy clay loam		
Temp.(°C)*	$26.34±0.18^{a}$	$25.88±0.20^{a}$	$26.81±0.11^{b}$	$25.64±0.16^{a}$	$25.78±0.18^{a}$	7.64	<0.01
pH*	$5.19±0.04^{ab}$	$5.07±0.05^{a}$	$5.32±0.07^{ab}$	$5.33±0.06^{b}$	$5.27±0.06^{ab}$	2.88	<0.01
Moisture (g%)*	$17.99±0.37^{a}$	$19.23±0.60^{b}$	$19.59±0.63^{ab}$	$21.03±0.45^{b}$	$17.86±0.61^{a}$	2.76	<0.01
O.carbon(g%)*	$1.06±0.06^{a}$	$1.10±0.03^{a}$	$1.46±0.04^{bc}$	$1.31±0.05^{bc}$	$1.00±0.03^{a}$	14.53	<0.01
O.matter(g%)*	$1.83±0.10^{a}$	$1.89±0.05^{a}$	$2.51±0.07^{bc}$	$2.26±0.09^{bc}$	$1.72±0.06^{a}$	14.27	<0.01
Av.N(kg/ha)	$439.04±12.54^{a}$	$558.20±6.27^{b}$	$595.84±6.27^{b}$	$558.20±6.27^{b}$	$570.75±6.27^{b}$	58.87	<0.01
Av.P (kg/ha)	$1.32±0.02^{a}$	$1.19±0.01^{b}$	$0.85±0.01^{c}$	$0.82±0.01^{c}$	$0.82±0.02^{c}$	195.88	<0.01
Av.K(kg/ha)	$228.49±0.01^{a}$	$198.22±0.02^{b}$	$283.37±0.01^{c}$	$270.54±0.5^{d}$	$395.33±0.03^{e}$	112462.35	<0.01
WHC (g%)*	$24.40±0.58^{a}$	$27.88±0.78^{b}$	$27.01±0.62^{ab}$	$29.15±0.65^{b}$	$26.51±1.03^{ab}$	5.83	<0.01
Bulk.den (g cm^{-3})*	$1.43±0.03^{a}$	$1.34±0.03^{a}$	$1.42±0.02^{a}$	$1.36±0.02^{a}$	$1.36±0.04^{a}$	2.05	>0.01
Litter prod. (g/m^2)*	$822.10±106.60^{a}$	$881.90±87.84^{a}$	$514.92±57.02^{b}$	$547.48±34.49^{abc}$	$767.42±61.35^{ab}$	5.03	<0.01
Cast prod. (g/m^2).*	$474.91±52.14^{a}$	$684.74±91.10^{a}$	$490.02±73.40^{a}$	N.D	$816±81.54^{a}$	2.57	>0.01
Earthworm Density (No/m^2)*	$73.82±3.93^{a}$	$175.09±18.46^{b}$	$108.68±11.22^{ac}$	$96.57±8.57^{a}$	$117.14±6.64^{ac}$	11.79	<0.01
Earthworm Biomass (g/m^2)*	$31.26±2.64^{a}$	$75.69±6.22^{b}$	$36.65±3.27^{a}$	$36.71±2.87^{a}$	$36.66±2.78^{a}$	22.70	<0.01
Shannon $\hat{H}$ **	$1.672±0.14^{a}$	$1.288±0.16^{a}$	$1.271±0.19^{a}$	$1.08±0.33^{a}$	$1.46±0.16^{a}$	3.83	>0.05
Dominance**	$0.223±0.03^{a}$	$0.371±0.03^{a}$	$0.365±0.07^{a}$	$0.49±0.16^{a}$	$0.31±0.05^{a}$	4.46	>0.05
Evenness**	$0.736±0.01^{a}$	$0.437±0.02^{a}$	$0.618±0.12^{a}$	$0.47±0.14^{a}$	$0.61±0.05^{a}$	5.86	>0.05
Species richness**	$0.695±0.13^{a}$	$0.598±0.18^{a}$	$0.613±0.06^{a}$	$0.66±0.22^{a}$	$0.70±0.06^{a}$	0.83	>0.05
No. of weed species	33	5	11	14	7		
No. of earthworm species found	10	16	10	12	11		
Exotic vs. native species ratio	2/8=0.25	4/12=0.33	2/8=0.25	5/7=0.71	4/7=0.57		
Anthropogenic interference	++	++++	++	+++++	+++		

SE= standard error. ND- Not determined. For * one-way ANOVA and for** Kruskal-Wallis test was performed. Dissimilar alphabets as superscripts signify statistically significant differences as shown by Tukey's post-hoc test. Results are at 5% level of significance. ++, +++ signifies intensity of anthropogenic effect.

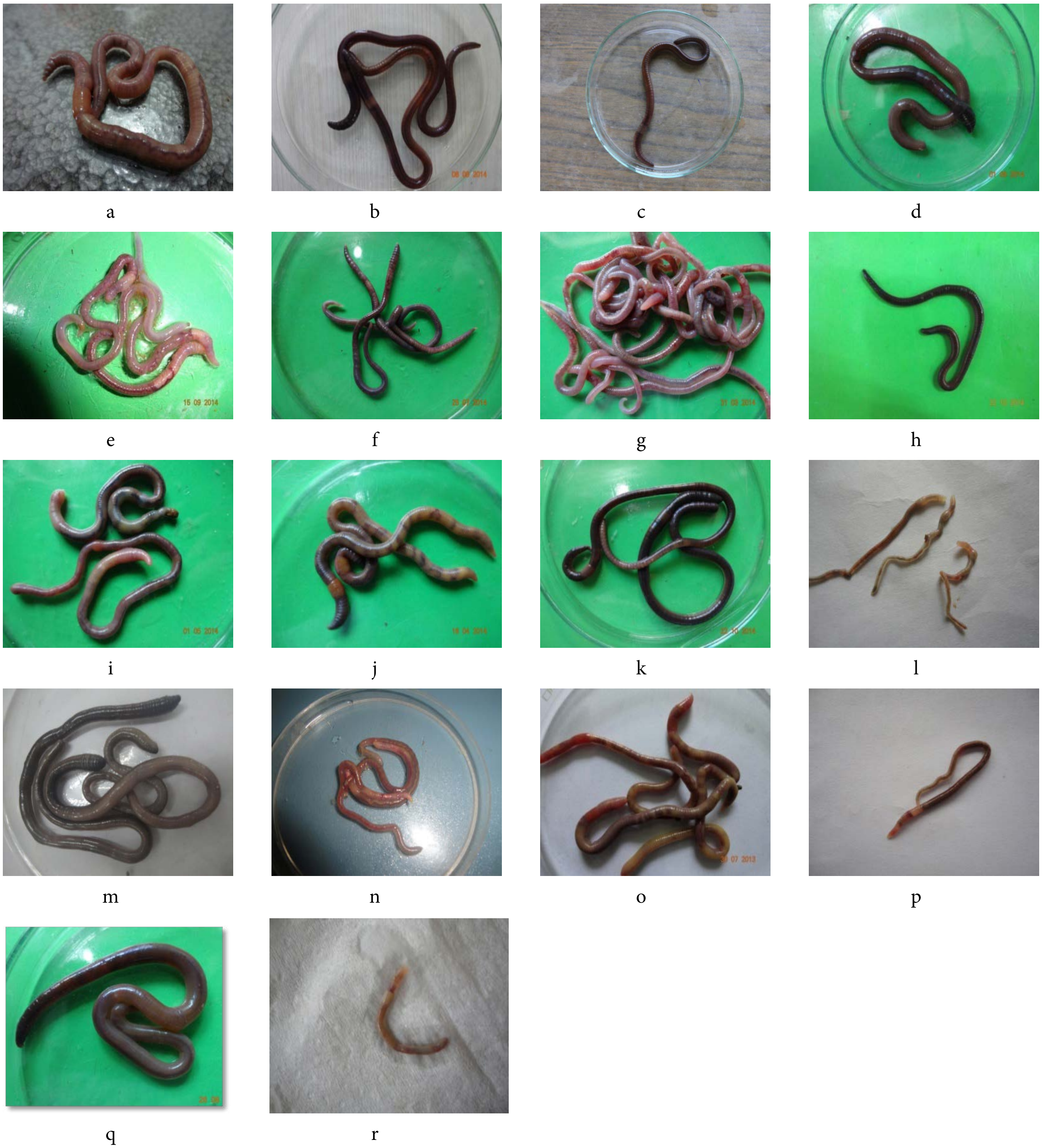


Figure 1. Photographs of different earthworm species under bamboo plantations of West Tripura- (a) *Eutyphoeus comillahnus* (b) *Amynthus alexandri* (c) *Metaphire posthuma* (d) *Eutyphoeus gigas* (e) *Drawida nepalensis* (f) *Drawida papillifer papillifer* (g) *Drawida assamensis* (h) *Perionyx excavatus* (i) *Kanchuria sp1* (j) *Lampito mauritii* (k) *Metaphire houlleti* (l) *Dicogaster bolaui* (m) *Eutyphoeus gammiei* (n) *Pontoscolex corethrurus* (o) *Octochaetona beatrix* (p) *Lennogaster chittagongensis* (q) *Eutyphoeus orientalis* (r) *Lennogaster chittagongensis.*

Ecological Categories

There were 3 ecological categories of earthworms in the bamboo plantations. Only 1 species was epigeic (*P. excavatus*), 4 species were anecic (*M. houlleti*, *A. alexandri*, *L. mauritii*, *D. papillifer papillifer*) and the rest 13 species were of endogeic categories. In spite of the fact that soils under all the species of bamboo plantations were always covered with bamboo leaf litter, number of epigeic (phytophagous) and anecic (phytogeophagous) species were remarkably less in them like that of *Hevea* plantations with deciduous litter fall (Chaudhuri and Nath, 2011). Less number of phytophagous earthworm species in the bamboo plantations was probably due to higher content of lignin (Table 2) which takes a long time for decomposition and being less suitable for earthworm consumption. Similarly high content of polyphenol was responsible for rare occurrence of epigeic and anecic earthworm species under rubber plantations (Chaudhuri *et al.,* 2013). Two anecic species, *M. houlleti*, *D. papillifer papillifer* and five endogeic species *viz. P. corethrurus*, *D. assamensis*, *Kanchuria* sp1, *E. comillahnus* and *O. beatrix* were found under all the five species of bamboo plantations. BB and BL each had 4 anecic species while BP, MB, BC had 3 anecic species each.

Earthworm Population Structure

Considering 5 different species of bamboo plantations, earthworms in general, had biomass of 43 g m^{-2} and density of 114 ind. m^{-2}. Highest density and biomass were found in BP (density 175 ind.m^{-2}, biomass 76 g m^{-2}) which were significantly higher ($P<0.05$) than those under other bamboo species (Table 1). Highest earthworm density in soils of BP was due to highest litter over surface, lowest soil bulk density, high moisture, low soil temperature and high organic matter content. Density and biomass of earthworm species under bamboo species plantations other than BP were at par ($P<0.05$).

Endogeic vs. Anecic Species

Density and biomass values of endogeic and anecic earthworm species under different species of bamboo plantations are given in Figure 2. Density and biomass of endogeic earthworms were much greater than those of anecic in BC, BP and BL plantations. Fragoso *et al.* (1999) advocated that earthworm communities of tropical ecosystems are composed of endogeic species of earthworms. Under tropical Indian conditions soil organic carbon is oxidized due to heat so that organic matter content is less which is quite suitable for endogeic species of earthworms (Kale, 1998). Plants provide important food resources to the earthworms in the form of dead roots, rhizosphere exudates and microorganisms associated with the decaying roots (Edwards and Bohlen 1996). Brown *et al.,* (2010) observed higher root density and a trend for more even distribution of roots in the soils both horizontally and vertically in presence of earthworms. Anecic species burrow more vertically and produce deeper channels which roots can follow. Roots can also enter and follow horizontal burrows produced by endogeic earthworms. Leon *et al.,* (2018) found a positive correlation between densities of most abundant endogeic earthworm, *Diplocardia* sp and previous-year production of fine roots which had a slower turnover rate. Litter feeding anecic earthworm population was negatively affected by high phenol, high lignin and low sugar contents in the leaf litter in BL and BC and positively affected by low contents of phenol, flavonoid,

Table 2. Chemical constituents of leaf-litter extracts of different bamboo species

Bamboo species	**Phenol (mgGAE/g plant extract)** Chloroform extract	**Flavonoids (mgQEE/g plant extract)** Chloroform extract	**Sugar (g/100g dry weight)**	**Lignin (percent/mg tissue)**	**Protein (mg/g tissue)**
B.cacharensis (BC)	3.79±0.62	2.14±0.22	3.17±0.33	10.28±0.19	13.54±0.14
B.polymorpha (BP)	3.69±0.08	2.43±0.23	3.24±0.54	13.89±0.13	1.76±0.08
M.baccifera (MB)	3.48±0.09	1.47±0.64	3.42±0.15	12.58±0.18	7.5±0.19
B.balcooa (BL)	3.97±0.18	1.79±0.05	2.97±0.08	13.03±0.20	14. 42±0.20
B.bambos (BB)	3.13±0.35	1.57±0.22	3.98±0.62	13.37±0.31	12.61±0.11

*Results are mean± SD from three sets of independent experiments, each set in triplicate.

Table 3. Species wise population and community characteristics of earthworms in different species of bamboo in West-Tripura

Name of the earthworm species and ecological category	Population /community characteristics	*Bambus cacharensis* (BC)	*Bambusa polymorpha* (BP)	*Melocanna baccifera* (MB)	*Bambusa balcooa* (BL)	*Bambusa bambos* (BB)
Megascolecidae	Density±S.E (No/m^2)	2.46 ± 0.60^{a}	18.46 ± 2.59^{b}	13.81 ± 2.38^{ab}	4.78 ± 1.05^{ab}	4.37 ± 1.10^{ab}
	Biomass±S.E (g/m^2)	2.34 ± 0.71^{a}	21.94 ± 3.71^{b}	14.17 ± 2.89^{bc}	5.14 ± 1.30^{a}	5.24 ± 1.45^{ac}
1 .*M. houlleti**	Frequency (%)	13.67^{a}	42.73^{a}	38.46^{a}	19.65^{a}	12.82^{a}
(Anecic)	Relative abundance (%)	4.98^{a}	17.97^{a}	36.59^{a}	5.57^{a}	9.75^{a}
	Community status	Subdominant	Dominant	Eudominant	Subdominant	Subdominant
	Density±S.E (No/m^2)	1.64 ± 0.56^{a}	0.41 ± 0.30^{a}	1.23 ± 0.44^{a}	0.54 ± 0.33^{a}	1.77 ± 0.54^{a}
2. *Kanchuria* sp-1	Biomass±S.E (g/m^2)	2.88 ± 1.08^{a}	0.50 ± 0.35^{a}	1.70 ± 0.64^{a}	0.85 ± 0.50^{a}	1.79 ± 0.58^{a}
(Endogeic)	Frequency (%)	7.69^{a}	1.70^{a}	6.83^{a}	2.56^{a}	9.40^{a}
	Relative abundance (%)	3.32^{a}	0.39^{a}	3.26^{a}	0.63^{a}	3.96^{a}
	Community status	Subdominant	Subrecedent	Subdominant	Subrecedent	Subdominant
	Density±S.E (No/m^2)	0.13 ± 0.13^{a}	n.f	0.13 ± 0.13^{a}	0.13 ± 0.13^{a}	0.68 ± 0.35^{a}
3. *L. mauritii*	Biomass±S.E (g/m^2)	0.11 ± 0.11^{a}	n.f	0.13 ± 0.13^{a}	0.06 ± 0.06^{a}	0.39 ± 0.22^{a}
(Anecic)	Frequency (%)	0.85^{a}	n.f	0.85^{a}	0.85^{a}	3.41^{a}
	Relative abundance (%)	0.27^{a}	n.f	0.63^{a}	0.15^{a}	1.52^{a}
	Community status	Subrecedent		Subrecedent	Subrecedent	Recedent
	Density±S.E (No/m^2)	n.f	1.23 ± 0.55^{a}	n.f	0.54 ± 0.26^{a}	0.68 ± 0.30^{a}
4. *A. alexandri**	Biomass±S.E (g/m^2)	n.f	4.41 ± 2.41^{a}	n.f	1.36 ± 0.68^{a}	2.41 ± 1.08^{a}
(Anecic)	Frequency (%)	n.f	5.12^{a}	n.f	2.56^{a}	4.27^{a}
	Relative abundance (%)	n.f	1.19^{a}	n.f	0.63^{a}	1.52^{a}
	Community status	-	Recedent	-	Subrecedent	Recedent
	Density±S.E (No/m^2)	n.f	0.41±0.30	n.f	n.f	n.f
5. *P.excavatus*	Biomass±S.E (g/m^2)	n.f	0.11±0.08	n.f	n.f	n.f
(Epigeic)	Frequency (%)	n.f	1.70	n.f	n.f	n.f
	Relative abundance (%)	n.f	0.39	n.f	n.f	n.f
	Community status	-	Subrecedent	-	-	-
	Density±S.E (No/m^2)	n.f	n.f	n.f	1.77±0.96	n.f
6. *M.posthuma**	Biomass±S.E (g/m^2)	n.f	n.f	n.f	2.01±1.06	n.f
(Endogeic)	Frequency (%)	n.f	n.f	n.f	4.27	n.f
	Relative abundance (%)	n.f	n.f	n.f	2.07	n.f
	Community status	-	-	-	Recedent	-
Octochaetidae	Density±S.E (No/m^2)	0.41 ± 0.30^{a}	0.27 ± 0.27^{a}	0.27 ± 0.19^{a}	0.95 ± 0.52^{a}	n.f
	Biomass±S.E (g/m^2)	1.78 ± 1.46^{a}	1.02 ± 1.02^{a}	1.25 ± 0.88^{a}	1.12 ± 0.55^{a}	n.f
7. *E. gigas*	Frequency (%)	1.70^{a}	0.85^{a}	1.70^{a}	3.41^{a}	n.f
(Endogeic)	Relative abundance (%)	0.83^{a}	0.26^{a}	0.72^{a}	1.11^{a}	n.f
	Community status	Subrecedent	Subrecedent	Subrecedent	Recedent	-
	Density±S.E (No/m^2)	5.60 ± 1.06^{a}	1.23 ± 0.55^{a}	0.54 ± 0.54^{b}	0.82 ± 0.50^{ab}	1.36 ± 0.60^{a}
	Biomass±S.E (g/m^2)	3.98 ± 0.94^{a}	1.21 ± 0.59^{b}	0.58 ± 0.58^{b}	0.85 ± 0.49^{b}	0.85 ± 0.41^{b}
8. *E. comillahnus*	Frequency (%)	22.22^{a}	2.56^{a}	0.85^{a}	2.56^{a}	4.27^{a}
(Endogeic)	Relative abundance (%)	11.35^{a}	1.19^{b}	1.44^{b}	0.95^{b}	3.04^{ab}
	Community status	Dominant	Recedent	Recedent	Subrecedent	Recedent
	Density±S.E (No/m^2)	n.f	0.41 ± 0.41^{a}	0.13 ± 0.13^{a}	n.f	n.f
9. *E. orientalis*	Biomass±S.E (g/m^2)	n.f	1.74 ± 1.74^{a}	0.76 ± 0.76^{a}	n.f	n.f
(Endogeic)	Frequency (%)	n.f	0.85^{a}	0.85^{a}	n.f	n.f
	Relative abundance (%)	n.f	0.39^{a}	0.36^{a}	n.f	n.f
	Community status	-	Subrecedent	Subrecedent	-	-

10. *E.gammiei*	Density±S.E (No/m^2)	n.f	0.95±0.48	n.f	n.f	n.f
(Endogeic)	Biomass±S.E (g/m^2)	n.f	3.44±1.89	n.f	n.f	n.f
	Frequency (%)	n.f	3.41	n.f	n.f	n.f
	Relative abundance (%)	n.f	0.93	n.f	n.f	n.f
	Community status	-	Subrecedent	-	-	-
11. *O. beatrix*	Density±S.E (No/m^2)	1.77±1.25^{a}	0.13±0.13^{b}	0.13±0.13^{b}	1.77±0.69^{b}	0.68±0.35^{b}
(Endogeic)	Biomass±S.E (g/m^2)	0.94±0.76^{a}	0.01±0.01^{a}	0.04±0.04^{a}	1.16±0.44^{a}	0.65±0.37^{a}
	Frequency (%)	1.70^{a}	0.85^{a}	0.85^{a}	6.83^{a}	3.41^{a}
	Relative abundance (%)	3.60^{a}	0.13^{a}	0.36^{a}	2.07^{a}	1.52^{a}
	Community status	Subdominant	Subrecedent	Subrecedent	Recedent	Recedent
12. *D. bolaui**	Density±S.E (No/m^2)	n.f	0.13±0.13^{a}	n.f	0.13±0.13^{a}	0.13±0.13^{a}
(Endogeic)	Biomass±S.E (g/m^2)	n.f	0.005±0.005^{a}	n.f	0.008±0.008^{a}	0.001±0.001^{a}
	Frequency (%)	n.f	0.85^{a}	n.f	0.85^{a}	0.85^{a}
	Relative abundance (%)	n.f	0.13^{a}	n.f	0.15^{a}	0.30^{a}
	Community status	-	Subrecedent	-	Subrecedent	Subrecedent
13. *L.*	Density±S.E (No/m^2)	n.f	0.41±0.41^{a}	n.f	n.f	0.13±0.13^{a}
chittagongensis	Biomass±S.E (g/m^2)	n.f	0.03±0.03^{a}	n.f	n.f	0.01±0.01^{a}
(Endogeic)	Frequency (%)	n.f	0.85^{a}	n.f	n.f	0.85^{a}
	Relative abundance (%)	n.f	0.39^{a}	n.f	n.f	0.30^{a}
	Community status	-	Subrecedent	-	-	Subrecedent
14. *L. yeicus*	Density±S.E (No/m^2)	1.23±0.91^{a}	0.41±0.41^{a}	n.f	n.f	n.f
(Endogeic)	Biomass±S.E (g/m^2)	0.04±0.03^{a}	0.01±0.01^{a}	n.f	n.f	n.f
	Frequency (%)	1.70^{a}	0.85^{a}	n.f	n.f	n.f
	Relative abundance (%)	2.49^{a}	0.39^{a}	n.f	n.f	n.f
	Community status	Recedent	Subrecedent			
Moniligastridae	Density±S.E (No/m^2)	16.13±2.70^{a}	34.87±4.70^{b}	13.40±2.49^{a}	6.29±1.76^{ab}	17.9±3.03^{ab}
	Biomass±S.E (g/m^2)	4.76±0.86^{a}	18.12±3.00^{b}	4.45±1.15^{a}	1.96±0.56^{a}	4.12±0.78^{a}
15. *D. assamensis*	Frequency (%)	40.17^{a}	48.71^{a}	33.33^{a}	13.67^{a}	33.33^{a}
(Endogeic)	Relative abundance (%)	32.68^{a}	33.95^{a}	35.50^{a}	7.32^{a}	39.93^{a}
	Community status	Eudominant	Eudominant	Eudominant	Subdominant	Eudominant
16. *D. nepalensis*	Density±S.E (No/m^2)	n.f	0.27±0.27	n.f	n.f	n.f
(Endogeic)	Biomass±S.E (g/m^2)	n.f	0.23±0.23	n.f	n.f	n.f
	Frequency (%)	n.f	0.85	n.f	n.f	n.f
	Relative abundance (%)	n.f	0.26	n.f	n.f	n.f
	Community status	-	Subrecedent	-	-	-
17. *D. papillifer*	Density±S.E (No/m^2)	10.94±1.82^{a}	1.91±0.67^{a}	5.88±1.44^{a}	5.19±1.73^{a}	13.12±2.41^{a}
papillifer	Biomass±S.E (g/m^2)	4.33±0.74^{a}	0.62±0.23^{a}	2.12±0.53^{a}	1.67±0.5^{a}	4.38±0.92^{a}
(Anecic)	Frequency (%)	22.22^{a}	3.41^{a}	20.51^{a}	11.96^{a}	31.62^{a}
	Relative abundance (%)	22.16^{a}	1.80^{a}	15.57^{a}	6.05^{a}	29.26^{a}
	Community status	Dominant	Recedent	Dominant	Subdominant	Dominant
Glossoscolicidae	Density±S.E (No/m^2)	9.02±2.40^{a}	44.85±4.92^{b}	2.18±0.74^{a}	62.90±9.14^{c}	3.96±1.39^{a}
	Biomass±S.E (g/m^2)	2.56±0.65^{a}	13.60±1.68^{b}	0.40±0.13^{a}	15.27±1.96^{b}	1.46±0.49^{a}
18. *P. corethrurus**	Frequency (%)	19.65	56.41	9.40	63.24	10.25
(Endogeic)	Relative abundance (%)	18.28^{a}	40.07^{a}	5.79^{a}	73.24^{a}	8.84^{a}
	Community status	Dominant	Eudominant	subdominant	Eudominant	Subdominant

Dissimilar alphabets as superscripts signify statistically significant differences as shown by Tukey's post-hoc test. Results are at 5% level of significance. n.f=not found. *Exotic species.

lignin and high sugar content in the leaf litter of MB, BP and BB (Table 2). Satchell (1967) showed that there was an inverse correlation between the palatability of litter and its total phenol content.

Correlation between Population Structure and Litter Fall

High earthworm biomass value in BP and low earthworm biomass values in BC, MB, BL and BB plantations were probably linked with high litter accumulation in the former and low litter accumulation in the latter. Leon *et al.*, (2018) observed positive correlation between densities of endogeic earthworm, *Diplocardia* sp and previous year production of leaf litter.

Earthworm Community Characteristics: Species Richness, Diversity, Dominance, Evenness, Similarity Index

Number of earthworm species in the earthworm community in the bamboo plantation varied from 10 to 16 species (BC-10 species, MB-10 species, BB-11 species, BL-12 species, BP-16 species). This is well within the reported range of 1 to 15 species in a given earthworm community (Edwards and Bohlen, 1996). Likewise Dey and Chaudhuri (2014) reported 11 species in the pineapple plantation and 14 species in the mixed fruit plantations. Recently Jamatia and Chaudhuri (2017a) reported a range of 5 to 9 earthworm species in the tea plantations of Tripura. Haokip and Singh (2017) recently

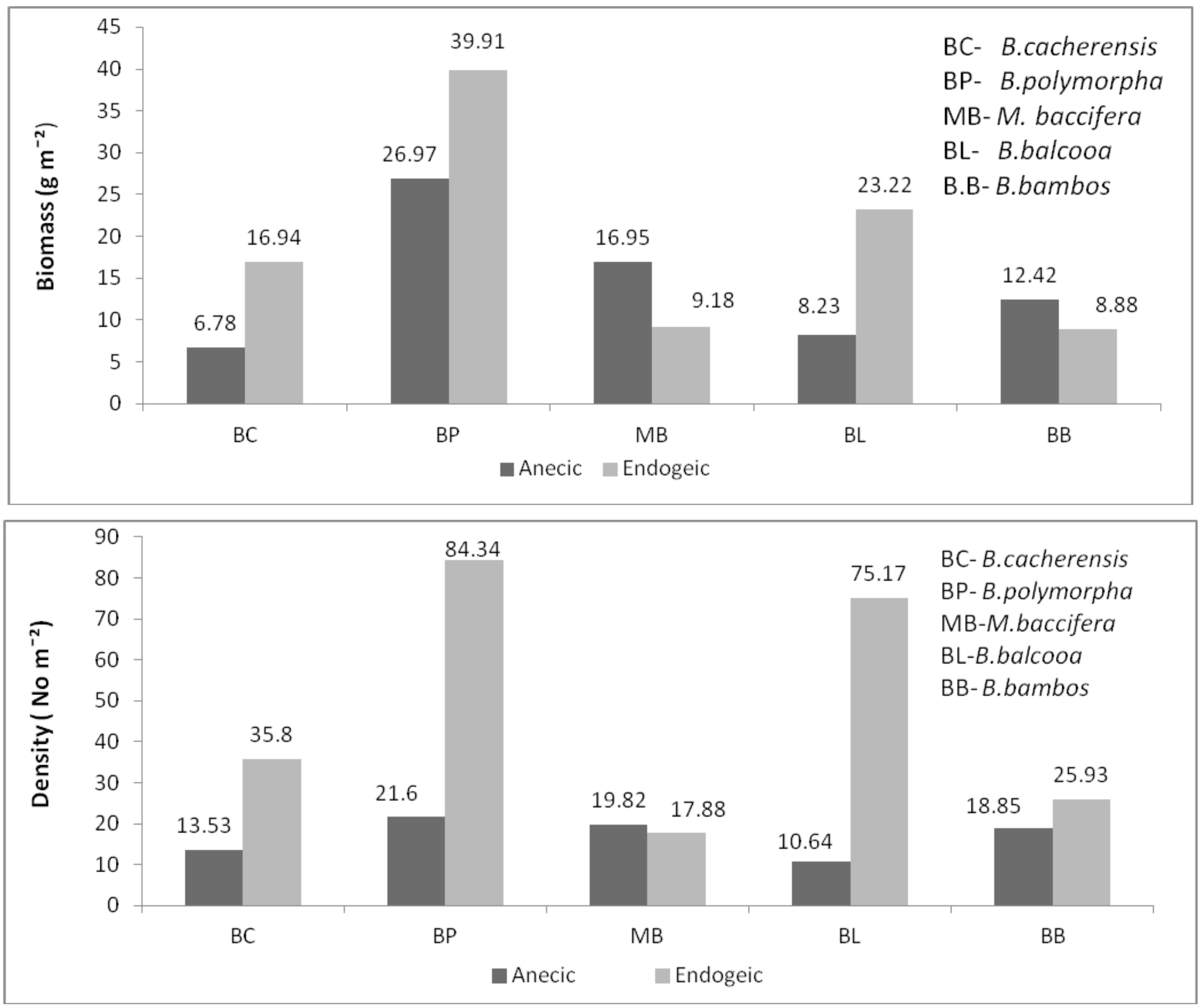


Figure 2. Bar diagram showing earthworm biomasses (g m^{-2}) and densities (No m^{-2}) of anecic and endogeic ecological categories under soils of different bamboo plantations.

reported occurrence of 12 earthworm species in reserve mixed forest and only 4 species in the oak plantation forest of Manipur of northeast India. The difference in species composition among different habitats indicates the importance of habitat heterogeneity (β-diversity) in the diversity of earthworms (Fragoso and Lavelle, 1987; Goswami and Mondal, 2015).

Shannon diversity indices ($\hat{H}$) varied from the lowest of 1.08 in the BL with comparatively higher anthropogenic interference to the highest of 1.67 in the BC with lowest human activities (Table 1). Earthworm species diversity indices in the studied bamboo plantations are much higher than those of pasture (0.39) of Western Ghats (Blanchart and Julka, 1997), paddy plantations (0.45) of Kashmir Valley (Najar and Khan, 2011), orchard (0.66) (Suthar, 2011), grazed grassland (0.68) (Goswami and Mondal, 2015), rubber plantation (0.86) (Chaudhuri and Nath, 2011), pineapple (0.67) (Dey and Chaudhuri, 2014), tea (0.72) (Jamatia and Chaudhuri, 2017a) of Tripura. The $\hat{H}$ values are however much closer to that of flower gardens (1.09) of Kashmir Valley (Najar and Khan, 2011), plain protected pasture (1.21) (Sahu, 1989), waste land (1.22) of Rajasthan (Suthar, 2011), subtropical oak plantation (1.27) of Manipur (Haokip and Singh, 2017), tree plantation (1.58) of Rajasthan (Suthar, 2011) , mixed fruit plantation (1.57) (Dey and Chaudhuri, 2014) and mixed forest (1.76) (Chaudhuri and Nath, 2011) of Tripura. BC plantation with highest earthworm diversity index (1.67) is probably associated with largest diversity of weeds (Table 1). This indicates that environmental heterogeneity is important in promoting earthworm diversity (beta diversity) as advocated by Fragoso and Lavelle (1987). According to Shakir and Dindal (1997) population density of earthworms is negatively correlated with species diversity. Thus, BP with highest earthworm population density had lesser diversity and BC with highest Shannon diversity had lowest earthworm density (Table 1).

Anthropogenic interference is negatively correlated with earthworm species diversity (Chaudhuri and Nath, 2011; Jamatia and Chaudhuri, 2017b). Thus BC with lowest anthropogenic interference had highest diversity. Increase in the number of exotic species (4 in BP, 5 in BL) coupled with higher dominance indices and greater relative abundance of exotic species, *Pontoscolex corethrurus* led to lesser diversity in BP and BL which also had the highest anthropogenic disturbance. *P. corethrurus* has already been considered as an invasive species leading to higher dominance and lesser diversity in the rubber plantations of Tripura (Nath and Chaudhuri, 2010). BP, in spite of having highest number of earthworm species (16), had less diverse community due to its highest earthworm population density, higher dominance, lowest overground weed diversity and least evenness compared to those of other plantations (Table 1). On the other hand BC had the highest diversity index (1.67) in spite of having lowest number of earthworm species (10) which was due to the fact that here dominance was shared by four earthworm species such as *E. comillahnus* (11% relative abundance), *D. assamensis* (33% relative abundance), *D. papillifer papllifer* (22% relative abundance) and *P. corethrurus* (18% relative abundance).

Earthworm species richness indices varied from 0.59 in BP to 0.70 in BB (Table 1). Species richness in BC (0.69) and BB (0.70) is comparable to those of mixed fruit plantations (0.69) in Tripura (Dey and Chaudhuri, 2014) and upland protected pasture (0.73) (Senapati and Dash, 1981), mixed tree plantations (0.74) (Suthar, 2011) but much higher than Paddy (0.13), flower garden (0.32) (Najar and Khan, 2011) of Kashmir Valley and rubber (0.45) (Chaudhuri and Nath, 2011), pineapple (0.33) (Dey and Chaudhuri, 2014) and tea plantation (0.43) (Jamatia and Chaudhuri, 2017a) of Tripura.

The habitat similarity of the earthworm species or the bamboo plantation was compared using Bray-Curtis cluster analysis. Based on Bray-Curtis single cluster analysis (Figure 3), the most similar communities are BC and BB plantations having a similarity coefficient of 78% where as BL and BP are the most distinct clusters having about 60% similarity among themselves. The similarity between BC and BB plantations can be attributed to a number of factors like similar topography, comparatively less anthropogenic interference, very similar species richness and comparatively lesser community dominance by few species (Table 1). Because of their high commercial viability and growth in topographically plain habitats, BL and BP plantations are the most anthropogenically disturbed communities containing a substantial proportion of exotic species. MB plantations are more closer to BB and BC plantation compared to BL and BP plantations in terms of community composition because of their occurrence in topographically different habitats (in higher elevations in slopes) having least anthropogenic influence. Moreover, non-clumping habit of this bamboo species (MB) might have also attributed to different microhabitat conditions affecting the earthworm species composition.

Absence of any significant difference in the earthworm diversity indices, species richness indices, dominance, evenness etc among different bamboo plantations (Table 1) is probably due to similar soil microhabitat conditions under those plantations.

Community Wise Rank of Earthworm Species

Rank abundance curves of earthworm species under different species of bamboo plantations are shown in Figure 4. The highest rank of *D.assamensis* in BC, BB, *P. corethrurus* in BP, BL and *M. houlleti* in MB plantations in the rank abundance curve reveals their survival superiority and probably a strong competitive edge over the other earthworm species. Higher frequency in the distribution of *D. papillifer papillifer* in BC, MB, BB, *P. corethrurus* in BP, BL, *M. houlliti* in BP, MB and *E. comillahnus* in BC indicate greater uniformity in distribution in their respective habitats. The curves also illustrate clearly that bamboo plantations having more even distribution (evenness) of earthworm species show gradual and gentle slopes as in BC, whereas plantations (such as BL) having low evenness, are mostly dominated by one or few species, display steeper slopes with skewed assemblage of species.

Sarlo (2006) advocated 'individual tree species effect' on the tropical earthworm species population in Panama. In spite of the fact that BC, BB, BP and BL belong to 4 different species under same genus *Bambusa*, they had only 2 preferred earthworm species such as *D. assamensis* and *P. corethrurus* in their soils. Highest rank of *P. corethrurus* in BP and BL was due to higher anthropogenic interference in them, while highest rank of *D. assamensis* was found in BC and BB plantations with lesser human activities. That high anthropogenic activities lead to higher dominance of exotic earthworm *P. corethrurus* was advocated by Chaudhuri *et al.* (2008) in rubber plantation and tea plantation (Jamatia and Chaudhuri, 2017 b) and low anthropogenic interference lead to dominance of native species *D. assamensis* in pineapple plantation was advocated by Dey and Chaudhuri (2014). Moreover, wide occurrence of both *P. corethrurus* and *D. assamensis* with higher relative abundance and also their coexistence in the soils of different monoculture plantations in Tripura (Chaudhuri *et al.*, 2008; Dey and Chaudhuri 2014; Jamatia and Chaudhuri, 2017 a, b) was due to their wide range of

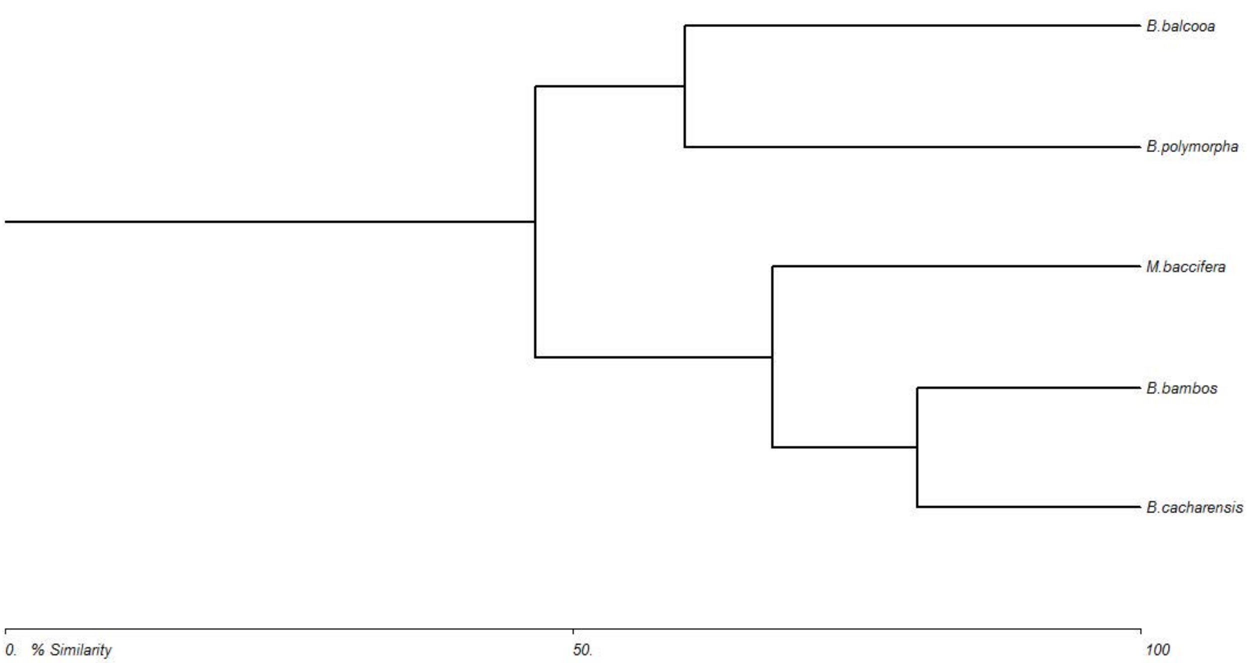
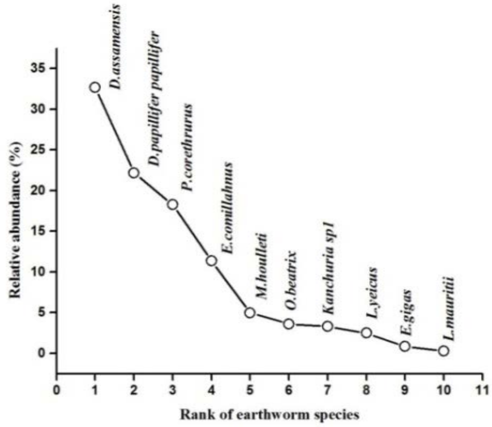
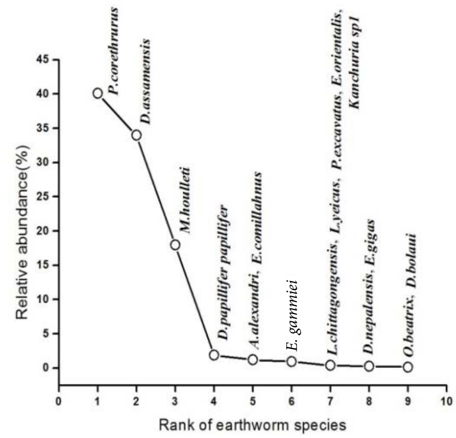


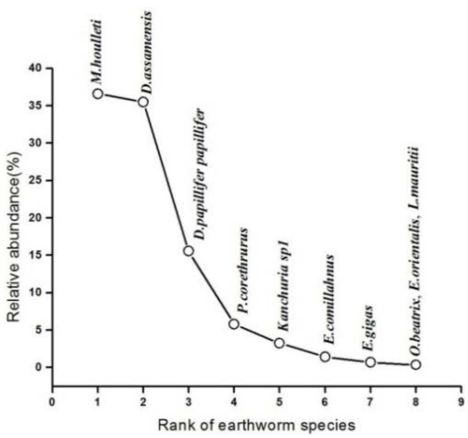
Figure 3. Bray-Curtis single cluster analysis based on earthworm community composition in the different bamboo plantations.



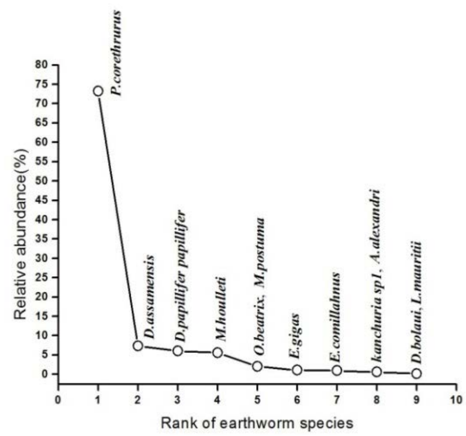
(a) ***Bambusa cacharensis***



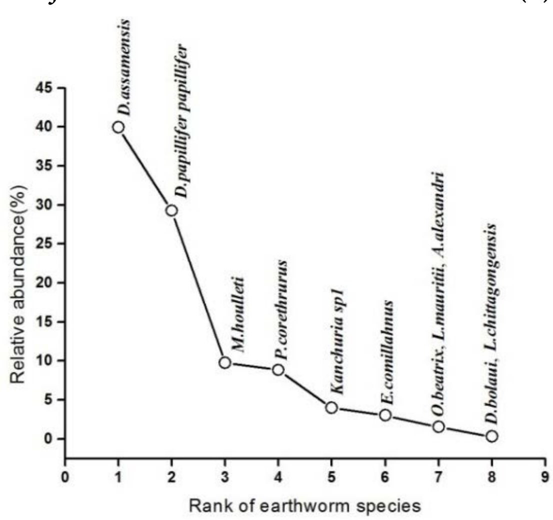
(b) *Bambusa polymorpha*



(c) ***Melocanna baccifera***



(d) *Bambusa balcooa*



(e) *Bambusa bambos*

Figure 4. Rank abundance curves showing abundance patterns of earthworm species in soils under different species of bamboo plantations.

ecological tolerance (Chakraborty and Chaudhuri, 2017). Thus intensities of anthropogenic interferences and ecological tolerance of earthworm species are probably the most important factors that regulate the distribution of earthworm species in monoculture plantations.

Differential Earthworm Casting Activities under Bamboo Plantations

In a given area earthworm activity is indicated by production of overground casts (Edwards and Bohlen, 1996). Thus high cast production in BP (685 g m^{-2}) and BB (816 g m^{-2}) was reflected by high earthworm density values in these plantations (BP 175 ind. m^{-2}, BB 117 ind. m^{-2}). Higher cast production in spite of significantly less ($P<0.05$) earthworm density in BB than BP was probably due to lesser anthropogenic effect in the former than the latter. Due to high human activities in BL, no detectable casts were recorded there. BC and MB plantations had low surface cast production associated with lesser earthworm density values. Casts of tropical earthworms contain higher organic carbon than surrounding soil (Chaudhuri *et al.,* 2009; Hmar and Ramanujam, 2014). Earthworms accelerate carbon activation and induce unequal amplification of carbon stabilization compared to carbon mineralization, which generates an earthworm mediated 'carbon trap' (Zhang *et al.,* 2013). Interestingly, Don *et al.* (2008) advocated important role of anecic earthworms in increasing carbon sequestration and thereby accumulation in their vertical burrows that serve as fast ways for fresh carbon transport in the deep soil horizon. Thus relative increase in density and biomass of anecic earthworms compared to endogeic in MB plantations among 5 species of bamboos might have links with their role in carbon storage in soil earthworm burrow systems.

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