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Earthworm community structure under tea plantations (*Camellia sinensis*) of Tripura (India)

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Abstract: A study of the community structure of earthworms under the tea plantations (*Camellia sinensis*) in four districts of Tripura revealed 15 species of earthworms from four families viz. Octochaetidae (*Eutyphoeus comillahnus, Eutyphoeus* sp. 1*, Eutyphoeus orientalis, Lennogaster yeicus, Lennogaster chittagongensis, Dichogaster bolaui, Dichogaster affinis, Octochaetona beatrix*), Megascolecidae (*Metaphire houlleti, Kanchuria* sp. 1*, Amynthas alexandri, Polypheretima elongata*), Moniligastridae (*Drawida assamensis, Drawida papillifer papillifer*) and Glossoscolecidae (*Pontoscolex corethrurus*). These occurred within the top 15 cm of soils with a mean temperature of 26.9 °C, moisture content 16.2%, pH 4.92, organic matter content 2.13%, and the bulk density 1.09 g cm^{-3}. In general, mean density and biomass of earthworms, irrespective of their age groups, were 212 ind. m^{-2} and 51.7 g m^{-2}, respectively. Earthworm community showed co-existence of native species with the exotics, presence of only 2 ecological categories (endogeic and epianecic), low Shannon-Wiener diversity index (0.72), Menhinick species richness (0.43), and a high relative density (36.20%) of the exotic species, *Pontoscolex corethrurus*.

Key words: Earthworm community, tea plantations, biomass, density, diversity, dominance, exotic earthworm, species richness.

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Introduction

Agricultural intensification affects the community composition of soil fauna that regulate ecosystem functions (Bartz *et al.* 2014; Fragoso *et al.* 1997; Smith *et al.* 2008). Intensification is generally accompanied by greater perturbation, greater proportion of annual cropping and use of external inputs such as fertilizers, insecticides, fungicides and herbicides. Among the organisms affected by intensification are earthworms, considered important for soil functions and the delivery of ecosystem services (Bartz *et al.* 2014). In most cases, intensification negatively affects the biomass, density and species richness of earthworm communities (Ponge *et al.* 2013).

Anthropogenic interference often exerts serious impact on diversity, richness and dominance of earthworms in soil ecosystem (Chaudhuri & Nath 2011; Nath & Chaudhuri 2010). In fact, earthworm distribution and community structure are dependent upon the litter input and chemical characteristics of these inputs which vary with land management practices (Dash & Dash 2008). Chaudhuri *et al.* (2013) correlated earthworm density and biomass with soluble sugar, polyphenols, flavonoids and lignin contents in the leaf litter of rubber plantations.

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Interestingly, proliferation of the termite population at the expenses of earthworm population was reported by Senapati *et al.* (2005) in tea gardens in South India. Tea (*Camellia sinensis*, F. Theaceae) is an economically important, perennial evergreen and intensively managed monoculture plantation crop that grows under tropical and sub-tropical conditions, providing the congenial microclimate both above and below-ground fauna (Saha *et al.* 2012). Tripura is the 5th largest tea producing state following Assam, West Bengal, Tamil Nadu and Kerala among the 14 cultivating states in India (Source: Department of Industries and Commerce, Govt. of Tripura. 2014. http://industries.tripura.gov.in/tea). Tea leaf litter is less palatable to earthworms due to high contents of polyphenol (Harbowy & Balentine 1997). According to Edwards & Bohlen (1996), in earthworms, palatability has an inverse relationship with polyphenol contents of leaves. We, therefore, predicted that (1) exotic species which tolerates well the anthropogenic practices will dominate the tea plantations, and (2) there will be a decline in functional guild (ecological categories) diversity of earthworms including a decline in surface feeding earthworms due to litter quality. In the present paper, we tested these predictions with reference to the community structure of earthworms and their distribution in relation to physico-chemical parameters of soils under tea plantations in Tripura. This study was considered important because in view of scant information available on the species diversity and ecology of these ecosystem engineers in the tea plantations of India (Senapati *et al.* 2005).

Materials and methods

Study sites

The studies were conducted during June 2013 - November 2014 in the tea plantations in four districts of Tripura-West (Durgabari & Lembucherra), Khowai (Pohormura & Kalyanpur), Sipahijala (Harishnagar) and Unakoti (Chhantali). Tripura (22º51'–24º32'N and 90º10'–92º21'E), a north-eastern state of India having an area of 10,491 km^2 is bordered by Bangladesh to the north, south and west and Assam and Mizoram to the east. This region experiences a tropical climate with four seasons, namely summer (March - May), monsoon (June–September), autumn (October–November), winter (December–February), the mean annual rainfall is 2000 mm, and a mean temperature of 25 ºC (Dey & Chaudhuri 2014).

Study sites selected for earthworm survey comprised six (06) mature (more than 20 years old) tea plantations of both managed (03) and unmanaged (03) types. The distance between the sites ranged from 20–180 km. Moderate canopy covers of trees (*Albizia odoratissima*, *Albizia lucida, Albizia lebbeck*, *Derris robusta*, *Albizia chinensis* belonging to Fabaceae) are used as shades to tea plants. Plantation floors remain covered with partly decomposed tea leaf litter along with different weeds throughout the year. While managed tea plantations regularly face anthropogenic practices like regular plucking of tea leaves, periodical weeding, application of fertilizers and pesticides and annual pruning, the unmanaged plantations are devoid of such kind of activities.

Earthworm sampling

Earthworms were sampled (number of monoliths = 726) between June 2013 and November 2014 by conventional digging (25 cm × 25 cm × 30 cm) and hand-sorting using the quadrat method (Chaudhuri *et al.* 2008). Five widely separated 10 m × 10 m plots were selected for sampling of earthworms, both in plains and slopes at each study site. Sample points were marked at the four corners and a center of each sampling plot. Earthworms were counted, rinsed, and weighed (with gut content) on an electronic balance in the field. Some clitellate worms were preserved in 10% formalin for identification while others were released into soil for biodiversity conservation. Earthworm species were identified following taxonomic keys of Gates (1972) and Julka (1988). Results are expressed in terms of biomass (fresh weight, g m^{-2}) and density (ind. m^{-2}). Gut contents of earthworms were included during determination of their biomass.

Biomass and density under different age groups (juveniles, young non-clitellates and clitellates) of all the earthworm species recorded in the study were determined. Relative density, frequency (Dash & Dash 2009), diversity (Shannon & Wiener 1963), dominance (Simpson 1949), species richness (Menhinick 1964), and species evenness indices (Dash & Dash 2009) of clitellate earthworm communities were also calculated. The ecological categories of earthworms of the studied sites were also determined following Hendrix & Bohlen (2002). Intact casts of earthworms in

Table 1. Physico-chemical properties of soil and ecological parameters in tea plantation of Tripura.

Parameters	Tea plantation	
	Range	Mean ± S.E.
Temperature (°C)	19.2–30.6	26.89 ± 0.16
Moisture (%)	4.31–30.09	16.21 ± 0.19
pH	3.83–6.40	4.92 ± 0.02
Oxidizable carbon (%)	0.12–2.94	1.24 ± 0.02
Organic matter (%)	0.20–5.06	2.13 ± 0.04
Water holding capacity (%)	22.2–36.27	29.12 ± 0.48
Bulk density (g cm^{-3})	0.74–1.47	1.09 ± 0.01
Overall Earthworm density (ind. m^{-2})*	16–1040	212.75 ± 6.41
Density of adult (clitellate) worms (ind. m^{-2})	16–352	59.95 ± 4.65
Overall Earthworm biomass (g m^{-2})*	0.16–378.88	51.68 ± 1.79
Density of adult (clitellate) worms (ind. m^{-2})	0.48–208.16	27.55 ± 2.06
Cast production (g m^{-2})**	-	311.59 ± 8.83
Shannon's diversity index (Ĥ)	-	0.72
Simpson's index of dominance	-	0.23
Species evenness (J')	-	0.61
Menhinick species richness index (R)	-	0.43

* includes juveniles, youngs and adult clitellates, ** no. of samples = 100

general and exotic earthworms in particular were collected during June–September 2015 and the quantity of casts by dry weight (g m^{-2}) was determined.

Soil analysis

Soil samples (n = 150) for measuring physico-chemical parameters were collected from a depth of 0–15 cm by scraping the wall of the sampled quadrats. Soil temperature (soil thermometer) and soil moisture (gravimetric wet weight method) were recorded at each sample point (Chaudhuri *et al.* 2008). Collected soil samples were air-dried, crushed with mortar-pestle, passed through 2 mm mesh sieves, labelled and stored. These soil samples were analyzed for their pH (1:2.5 dilution method) and oxidizable organic matter contents (Walkley & Black 1934). Bulk density of soils was estimated using the 'core method' (Kalra and Maynard 1991). Soil texture was determined by the 'feel method' (Daji 1996).

Results

Pedobiological characteristics

The tea plantation soils were clay loam in texture. A total of 9267 earthworms (clitellate 1613, non-clitellate 4759, juveniles 2895) were collected (number of monoliths = 726) from the study sites. In general, high density of earthworms occurred in 0–15 cm soil depth. The mean values of physico-chemical and biological parameters of tea plantation soils from the six study sites viz. temperature, moisture, pH, organic matter, bulk density, water holding capacity, cast production, earthworm density and biomass are provided in Table 1.

Community composition

Ecological categories, habitats, morphological and population characteristics of different earthworm species are given in Table 2. A total of 15 species of earthworms from 10 genera and 4 families were collected from the studied sites. These comprised eight species of Octochaetidae [*Eutyphoeus comillahnus* (Michaelsen), *Eutyphoeus orientalis* (Beddard), *Eutyphoeus* sp.1, *Lennogaster yeicus* (Stephenson), *Lennogaster chittagongensis* (Stephenson), *Dichogaster bolaui* (Michaelsen), *Dichogaster affinis* (Michaelsen), *Octochaetona beatrix* (Beddard)], 4 species of Megascolecidae [*Metaphire houlleti* (Perrier), *Kanchuria* sp.1, *Amynthas alexandri* (Beddard), *Polypheretima elongata* (Perrier)], 2 species [(*Drawida assamensis* (Stephenson), *Drawida papillifer papillifer* (Gates)] of Moniligastridae, and 1 species [*Pontoscolex corethrurus* (Muller)] belonging to Glossoscolecidae, respectively. Six of these species namely, *P. corethrurus, M. houlleti, A. alexandri, P. elongata, D. bolaui* and *D. affinis*, were exotic and the rest native to the Indian

Table 2. Ecological categories, habitat, morphological and population characteristics of some adult earthworm species (number of monoliths = 726) of tea plantation in Tripura.

Family and earthworm species	Ecological category	Habitat (cm)	Size (L × D) (mm)	Biomass ($g\ m^{-2}$) Mean ± SE	Density ($ind.m^{-2}$) Mean ± SE	Relative density (%)	Frequency (%)
Octochaetidae							
Eutyphoeus comillahnus	Endogeic	0–15	118126 × 2-4	0.44 ± 0.26	0.36 ± 0.18	0.60	1.80
Eutyphoeus sp. 1	Endogeic	0–15	228 × 6	0.30 ± 0.30	0.07 ± 0.07	0.12	0.45
Eutyphoeus orientalis	Endogeic	0–20	194 × 4	0.11 ± 0.11	0.07 ± 0.07	0.12	0.45
Lennogaster chittagongensis	Endogeic	0–10	32-44 × 1-2	0.02 ± 0.01	0.21 ± 0.12	0.36	1.35
Lennogaster yeicus	Endogeic	0–10	31-42 × 1-2	0.03 ± 0.01	0.64 ± 0.34	1.08	2.25
*Dichogaster affinis**	Endogeic	0–10	19-21 × 1-2	0.02 ± 0.02	0.57 ± 0.45	0.96	0.90
*Dichogaster bolaui**	Endogeic	0–10	18-20 × 1-2	0.009 ± 0.008	0.14 ± 0.11	0.24	0.90
Octochaetona beatrix	Endogeic	0–15	54-136 × 2-4	1.43 ± 0.37	2.81 ± 0.81	4.68	9.90
Megascolecidae							
*Metaphire houlleti**	Epianecic	0–10	62-224 × 2-6	7.83 ± 1.23	11.6 ± 1.59	19.33	26.12
Kanchuria sp. 1	Endogeic	5–30	142-246 × 3-5	0.50 ± 0.27	0.28 ± 0.14	0.48	1.80
*Amynthus alexandri**	Epianecic	0–10	128-234 × 4-6	1.08 ± 0.73	0.36 ± 0.23	0.60	1.35
*Polypheretima elongata**	Endogeic	5–25	168-172 × 3-4	0.68 ± 0.39	0.21 ± 0.12	0.36	1.35
Moniligastridae							
Drawida assamensis	Endogeic	0–20	38-122 × 1-3	5.63 ± 0.69	14.34 ± 1.72	23.90	33.78
Drawida papillifer papillifer	Epianecic	0–15	48-136 × 1-2	2.44 ± 0.42	6.55 ± 1.14	10.92	18.46
Glossoscolecidae							
*Pontoscolex corethrurus**	Endogeic	0–20	46-112 × 1-3	7.03 ± 0.83	21.73 ± 2.47	36.22	46.39

* Exotic species; L = Length, D = Diameter

subcontinent. On the basis of length and diameter of the species, the largest and the smallest species of earthworms recorded in this study are *Amynthas alexandri* and *Dichogaster bolaui*, respectively. Earthworms belonged to two ecological categories, 3 species (*M. houlleti*, *A. alexandri* and *D. papillifer papillifer*) were epianecic (soil depth 0–10 cm) and the remaining 12 species (*Kanchuria* sp. 1, *P. elongata, D. assamensis, E. comillahnus, Eutyphoeus sp.*1, *E. orientalis, L. yeicus, L. chittagongensis, O. beatrix, P. corethrurus, D. bolaui and D. affini*s) were endogeic (soil depth 10–30 cm) (Table 2). Of the 3 epianecic species, two are exotic and one species is native. Overall density of earthworms (including juveniles, young and clitellate) in the tea plantation soils was 212.75 ± 6.41 ind. m^{-2}, with the adults (clitellate) sharing 59.94 ± 4.65 ind. m^{-2} (28% of total density) indicating major contributions of juveniles and non-clitellate in overall earthworm density. Likewise, overall biomass of earthworms was 51.68 ± 1.79 g m^{-2} of which adults contributed 27.55 ± 2.06 g m^{-2} (53 % of the total biomass). Earthworm species with highest and lowest population density were exotic *P. corethrurus* (21.73 ind. m^{-2}) and native *E. orientalis* (0.07 ind. m^{-2}), respectively. Ratios of exotic to native earthworm species density (ind. m^{-2}) were found to be 35:25, and that of biomass (g m^{-2}) was 17:10. Biomass and density of adult exotic species accounted for 60% and 58%, respectively, and those of natives were 40% and 42% in the soils of tea plantations in Tripura. Seasonal variations in the density and biomass of clitellate, non-clitellate young and juvenile earthworms along with soil moisture and soil organic matter in the tea plantations of Tripura are given in Fig. 1. While the density of juvenile earthworms gradually declined from March to November, that of non-clitellate young showed pronounced increase during monsoon followed by a sudden decline in the post-monsoon season. There was a gradual increase in density of adults from March to November. In this study, termite population with and without earthworms was also recorded.

Among the earthworm species recorded, 9 species were found at Durgabari (Sadar) and Chhantali (Kailasahar), 7 species each at Harishnagar (Bishalgarh) and Pohormura (Khowai), and 5 species at Lembucherra (Sadar). Interestingly, *P. corethrurus* was the only species found in all the sites studied with its adults in diapause stage during summer. Species of

Eutyphoeus, Drawida, Dichogaster, P. elongata, O. beatrix and *M. houlleti* showed restricted distribution in the tea plantations. Both the endogeic and epianecic void inorganic soil particles in the form of casts. Composite irregular-shaped casts were produced by *D. assamensis*, *D. papillifer papillifer* and *P. corethrurus*. Tower-like casts with thick, thread-like convolutions were produced by *M. houlleti*. The average mass (air-dried) of earthworm casts in the tea plantation floor was 311.59 ± 8.83 g m^{-2} but the two exotic species produced an average of 228.55 ± 4.80 g m^{-2} casts (73.34% of total cast production) (*P. corethrurus* casts 162.42 ± 4.97 g m^{-2} and *M. houlleti* casts 65.14 ± 4.52 g m^{-2}). Shannon diversity index (Ĥ), species richness index (R) and evenness (J') of earthworms were 0.72, 0.43 and 0.61 respectively (Table 1).

Relationship between earthworms and soil properties

In this study, wide range of tolerance to edaphic factors were exhibited by exotic *P. corethrurus* (temperature 20.2 ^{0}C–29.8 ^{0}C, moisture 9.35–29.8%, pH 4.01–5.7, organic matter 0.2–3.72%), *M. houlleti* (temperature 25.6 ^{0}C–29.0 ^{0}C, moisture 10.84–26.12%, pH 4.09–5.12, organic matter 1.29–2.13%) and by native *D. assamensis* (temperature 25.6–29.6 ^{0}C, moisture 10.84–26.12%, pH 4.09–6.31, organic matter 0.82–3.72%). In contrast, earthworm species viz. *E. comillahnus, Kanchuria* sp.1 and *Lennogaster* sp. showed narrow limits of tolerance to edaphic factors. Density and biomass of earthworms, in general, had a significant positive correlation (P < 0.05) with soil moisture and a negative correlation (P < 0.05) with soil temperature (Fig. 2a–d). Earthworm density also exhibited positive correlations (P < 0.05) with both soil pH and organic matter contents (Fig. 2e, f).

Discussion

Fifteen species of earthworms were recorded from the soils of tea plantations in Tripura in contrast to only six species recorded in the tea plantations from Tamil Nadu (Senapati *et al.* 2005). A maximum of nine and a minimum of five species were recorded in different studied sites of the tea plantations. The number of species in a given community, which is the simplest measure of species diversity, usually vary in a range of 4–14 species (Edwards & Bohlen 1996). Thus, earthworm species diversity from individual study sites of Tripura is well within the reported range. Out of the fifteen species, six are exotic viz. *P. corethrurus*, *M. houlleti*, *A. alexandri*, *P. elongata*, *D. bolaui* and *D. affinis* and the rest are endemic to the Indian sub-continent. Most of the exotic species of earthworms were introduced to India through anthropogenic activities or other agencies in soils around the roots of exotic plants during the British colonization (Chaudhuri *et al.* 2008; Julka 2014).

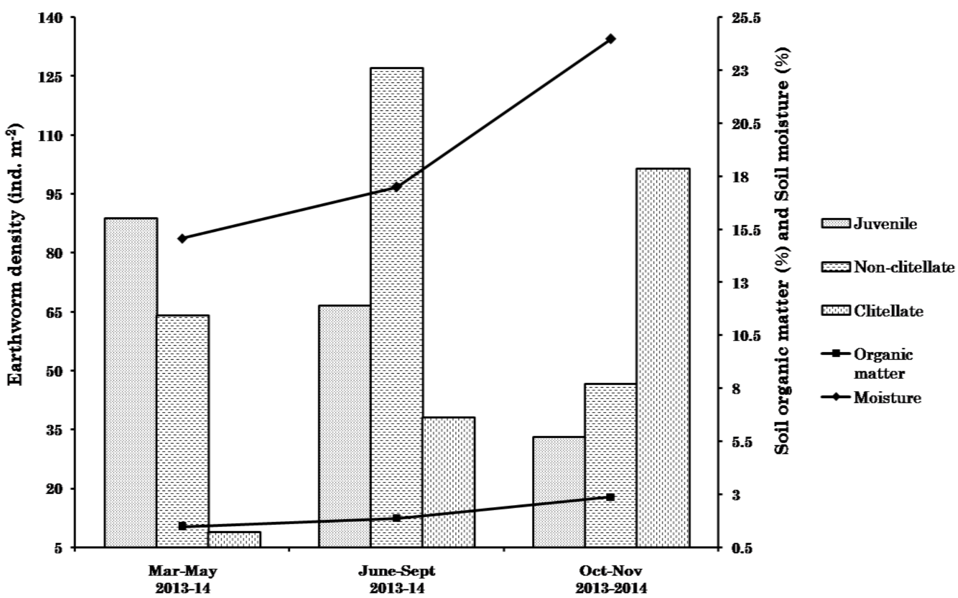

Fig. 1. Seasonal variations in the densities of clitellate, non-clitellate and juvenile earthworms along with soil moisture and soil organic matter in the tea plantations of Tripura.

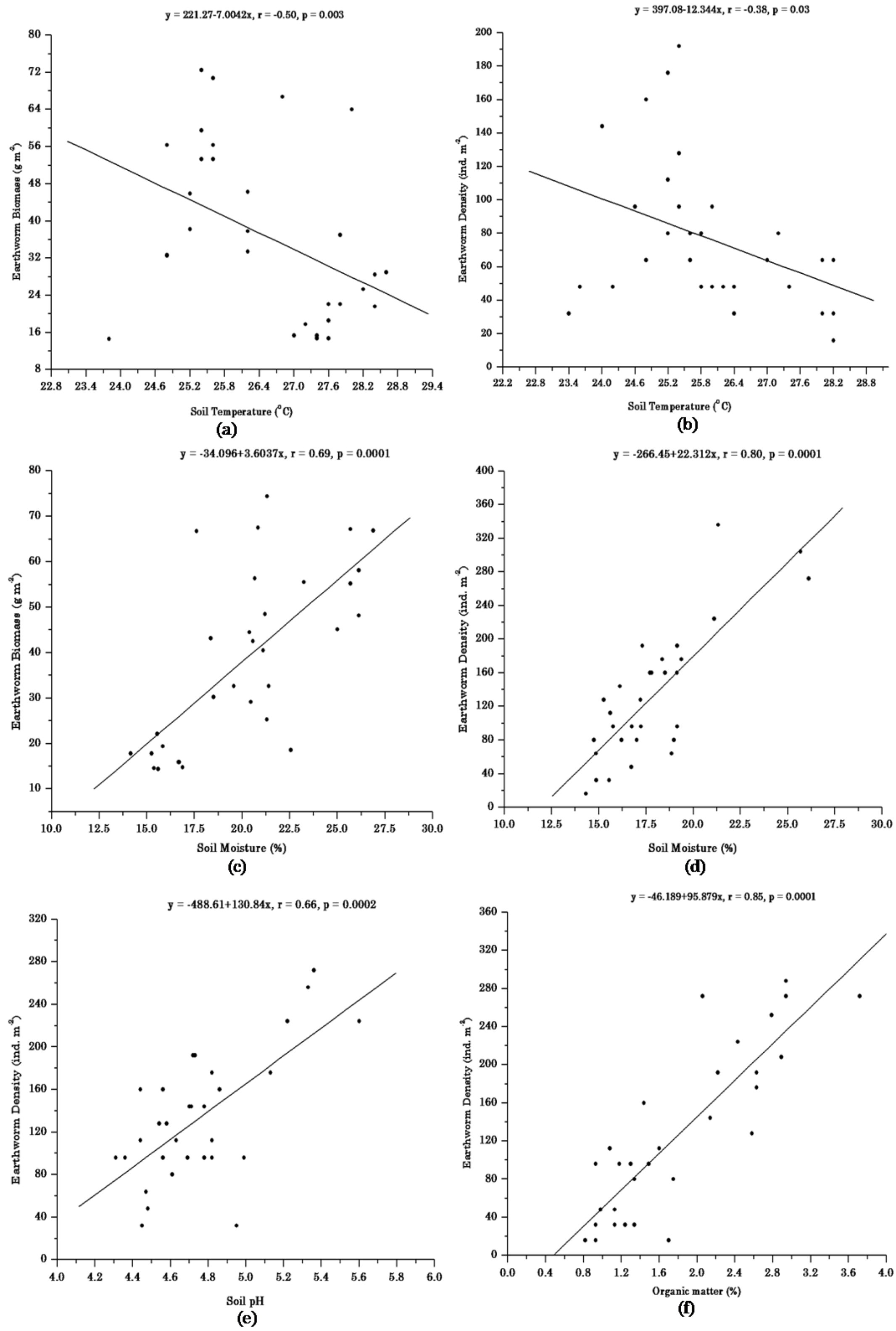

Fig. 2. Overall relationship between (a) earthworm biomass and soil temperature, (b) earthworm population density and soil temperature, (c) earthworm biomass and soil moisture, (d) earthworm population density and soil moisture, (e) earthworm population density and soil pH, (f) earthworm population density and soil organic matter content.

Senapati *et al.* (2005) reported proliferation of termites at the expense of native earthworm species leading to a severe decline in the population of the latter in the tea plantation soils of Tamil Nadu. Although termites with lesser abundance have also been found in the soils of the studied sites, their populations were not found to affect the native earthworm population. This may be attributed to good management practices in the tea plantations of Tripura.

Soils of tea agro-ecosystem have only two ecological categories of earthworms. Monoculture plantations with homogenous ecological niches exhibit less number of ecological categories (functional guild diversity) of earthworms than the forest ecosystem with varied ecological niches (Sinha *et al.* 2003). Tea agro-ecosystem is largely dominated by endogeic species (12 out of 15 species in this study). Absence of epigeic and presence of epianecic as a minor component (3 out of 15 species) of the earthworm community of tea plantations, in spite of the abundance of partly decomposed leaf litter in the plantation floor, are probably due to less palatability of tea leaf litter due to its high contents of polyphenols (Harbowy & Balentine 1997). Senapati *et al.* (1999) also reported significant depletion of leaf litter feeding epigeic and epianecic species of earthworms in the tea plantations of Tamil Nadu in comparison with its neighbouring forest.

Much higher values in the density and biomass of exotic (35 ind. m^{-2}, 25 g m^{-2}) and native (17 ind. m^{-2}, 10 g m^{-2}) species of earthworms indicate that disturbed habitat like tea plantations is quite hospitable for the former. Highest relative density and frequency of *P. corethrurus* among the earthworm species of tea plantation supports earlier report of Senapati *et al.* (2005) who also found this as the dominant earthworm species in the tea plantations of Tamil Nadu. Much higher cast production by the exotic species viz. *P. corethrurus* and *M. houlleti* (73% of total cast production) compared to native earthworms indicate that activity of exotics predominate the tea plantations. Successful establishment and dominance of these exotic earthworm species is primarily due to their inherent ability to withstand anthropogenic practices (Chaudhuri *et al.* 2008) and to tolerate wide range of edaphic factors in the tea plantation. Moreover, parthenogenetic mode of reproduction in *P. corethrurus* and *M. houlleti* (Chaudhuri & Bhattacharjee 2011) probably helped these to colonize tea plantations in Tripura. *P. corethrurus* has already acquired the status of 'invasive species' in disturbed habitats such as rubber plantation (Nath & Chaudhuri 2010). Contrary to the observation of Senapati *et al.* (2005), a good number of native species viz. *D. assamensis*, *D. papillifer papillifer*, *Kanchuria sp.*1, *E. comillahnus*, *E. orientalis*, *Eutyphoeus sp.*1, *L. chittagongensis*, *L. yeicus* and *O. beatrix* exist in the soils of tea plantations in Tripura. Co-existence of native species (although in low density and biomass) along with exotic earthworms could be traced to the fact that in Tripura fallow lands were converted into tea plantations so that original native earthworm species were retained.

Earthworm species diversity index ($\hat{H}$) under tea plantation (0.72) is comparable to those of other monoculture plantation like rubber (0.86) (Chaudhuri & Nath 2011) and pineapple (0.67) (Dey & Chaudhuri 2014) plantation in Tripura, but much lower than mixed forest (1.76) (Chaudhuri & Nath 2011), mixed fruit plantation (1.57) (Dey & Chaudhuri 2014), mixed tree plantation (1.58) (Suthar 2011) and forest (2.53) (Blanchart & Julka 1997). Species richness index (R) in tea plantation (0.43) is comparable to that of rubber plantation (0.45) with unpalatable leaf litter and severe anthropogenic interferences (Chaudhuri & Nath 2011) but much lower than mixed fruit (0.69) (Dey & Chaudhuri 2014) and mixed tree plantation (0.74) (Suthar 2011).

A number of edaphic factors are known to play a key role in the distribution, diversity and abundance of earthworms. The present study revealed the presence of earthworms in acidic soils (pH 4.92) with clay loam texture, average moisture 16.21%, temperature 26.89 °C, water holding capacity 29.12%, bulk density 1.09 g cm^{-3} and organic matter content 2.13%. Moisture and temperature in the soils of tea plantation had a significant positive and negative correlation ($P < 0.05$), respectively, with overall population density and biomass of earthworms. As earthworms are soft bodied organisms, they require moist conditions to maintain their hydrostatic pressure and to prevent desiccation (Najar & Khan 2014). A similar significant correlation was found between earthworm populations and temperature and moisture in the pineapple plantations of Tripura (Dey & Chaudhuri 2014). A significant positive correlation ($P < 0.05$) between earthworm densities and soil pH in tea plantations of Tripura supports the view of Lee (1985) that earthworms, in general, are neutrophilic. In fact, over ground large masses of partly decomposed tea leaf litter provide a mulching effect to support earthworm population. Strong positive correlation between earthworm population densities and soil organic matter in the present study supports Hendrix *et al.* (1992), Joshi *et al.* (2010) and Dey & Chaudhuri (2014) who also reported similar results.

Finally, change in the land use system in the form of tea agro-ecosystem led to decline in the number of litter feeding species, low diversity index, dominance of the exotic geophagous earthworm, *P. corethrurus* in tea plantation of Tripura. But the occurrence of a good number of native earthworm species in the soils of tea plantation indicates that the area of study belongs to the biodiversity hot-spot zone where native species are more resistant to disturbances and can co-exist with the exotics (Julka *et al.* 2009; Nath & Chaudhuri 2010).

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