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Impact of age of rubber (*Hevea brasiliensis*) plantation on earthworm communities of West Tripura (India)

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Abstract

A comparative analysis of earthworm communities was carried out in the rubber plantations (*Hevea brasiliensis*) of different age groups in West Tripura to understand the impact of such exotic and monoculture plantation in biodiversity conservation. Earthworm communities were studied on monthly basis over a period of one year (2006-2007) in the 3, 10, 14, 20 and 25 year-old plantations. Among twelve earthworm species collected from the studied sites, six species belonged to Octochaetidae [*Eutyphoeus assamensis* Stephenson, *Eutyphoeus comillahnus* Michaelsen, *Lennogaster chittagongensis* (Stephensen), *Octochaetona beatrix* Gates, *Dichogaster affinis* Michaelsen, *Lennogaster yeicus* (Stephensen)], two species each to Megascolecidae [*Metaphire houlleti* (Perrier), *Kanchuria* sp. 1] and Moniligastridae [*Drawida nepalensis* Michaelsen, *Drawida papillifer papillifer* Stephenson], one species each to Glossoscolecidae [*Pontoscolex corethrurus* (Muller)] and Ocnerodrilidae [*Gordiodrilus elegans* Beddard]. Exotic species *P. corethrurus, M. houlleti* and native peregrine species like *D. nepalensis* and *D. papillifer papillifer* were distributed in all the age groups of plantation, while other species showed restricted distribution. *P. corethrurus* contributed more than 60% biomass and 70% density of earthworm communities in rubber plantation. With aging of rubber plantations both the densities and biomasses of earthworms increased. High contents of polyphenol, flavonoid and lignin in the litters of 3 and 10 year-old-rubber plantations through their effects on food intake, probably resulted to low biomass values of earthworms in those age groups of plantation. With further increase in the age of plantations beyond 10 years, polyphenol, flavonoid and lignin contents decreased. Accordingly the biomass of earthworms increased with increase in the age of plantation. Soil moisture increased with increase in the age of plantation and there was a good positive correlation between soil moisture and earthworm biomass ($p<0.01$). Density, biomass and dominance of earthworms increased while species diversity, species richness and species evenness of earthworm community were decreased with increase in the age of rubber plantation.

Key words

Rubber plantation, Polyphenol, Lignin, Earthworm, Diversity

Introduction

In tropical and subtropical areas, tree plantations are being established for different land use systems viz. shift in timber production from native forests to plantation, restoration of degraded lands, catalysts of forest succession and also as buffer zones for biodiversity conservation (Sarlo, 2006).

In Tripura, a north eastern state of India, rubber (*Hevea brasilensis*) plantation was introduced in 1963 by the forest department to check soil degradation due to slash and burn agriculture practiced by the local tribal people. Rubber is an important cash crop in the economy of Tripura where it is cultivated in more than 40,000 ha area over hill slopes, hillocks and plains. Being a deciduous plant with very fast

growth and well canopy, it shows maximum litter addition to plantation floor amounting to 7 tons per hectare (Jacob, 2000). The litters are not generally removed but persist on the plantation floor throughout the year and show very slow rate of decomposition. According to Zhang *et al.* (2007), flow of rubber latex starts at 7 year age of plantation, becomes maximum at 20 years and typically ceases at 35 years. They reiterated that rubber plantation decreases soil organic carbon which is linked to latex harvesting.

Direct effect of plant species on soil organisms are caused by the plant's inputs of organic matter above and below the ground, while indirect effect of plants on biota include shading, soil protection and uptake of water and nutrients by the root (Neher, 1999). Satchell (1967) showed that there was an inverse correlation between the palatability of leaf litter and its total polyhydric phenol content and a positive correlation with the amount of soluble carbohydrate. Tien *et al.* (1993) reported that earthworm populations were negatively correlated with the ratio of lignin to nitrogen of the plant residues. According to Bernhard-Reversat and Loumetu (2002), the decomposition rate was negatively correlated with lignin content suggesting that the lignin content of the litter could control faunal consumption. Interestingly decrease in lignin and flavonoid content of plant with increase in plot age was reported by Arunachalam *et al*. (1996) and Howell *et al*. (1976) respectively. According to Chaudhuri *et al.* (2003), the quality and quantity of food material influences not only the size but also the species composition, growth rate, fecundity of an earthworm population. They reported differences in the rate of growth and reproduction of three vermicomposting species *Perionyx excavatus, Eudrilus eugeniae* and *Eisenia fetida* in the *Hevea* leaf litters used as vermiculture substrate. Since earthworms constitute the highest macro-fauna biomass in tropical soil (Fragoso and Lavelle, 1992), they play an important role in maintaining soil fertility, ecosystem function, production and biodiversity conservation (Chaudhuri *et al.,* 2012; Kavdir, 2011). Moreover earthworm can also be utilized as an effective tool in assessing the degree of anthropogenic influences such as afforestation and silvicultural practices (Chaudhuri and Nath, 2011).

According to Gonzalez *et al.* (1996) and Tien *et al*. (2000) tree plantations may influence earthworm abundance by altering the physico-chemical properties of soils *viz*. temperature, moisture regime, pH, organic matter content and litter inputs. 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 canopy cover. In fact, reports are scanty on the effect of the age of plantation on soil biota (Gilot *et al.,* 1995). Thus in the present paper, a comparative analysis of earthworm communities was carried out in the rubber plantation of different age groups in West Tripura to understand the impact of such exotic and monoculture plantation in conservation of earthworm diversity.

Materials and Methods

Study site: The study was carried out at Taranagar Rubber Research Farm ($23^0 53'$ N and $90^0 15'$ E) of Mohanpur Block, West Tripura with annual rain fall ranging from 1500-2000 mm. Different age groups (3, 10 , 14 , 20 and 25 years) of *Hevea* plantation were selected from a considerable large plantation area (86 ha) of Taranagar Rubber Research Farm. Replications were not kept due to non availability of same age group of plantation in the study area. Rubber plantation of different age groups (1.5 - 2.5 ha area) comprising of undulating landscapes with small uplands (locally called "tilla") were spatially isolated by a gap of 300 to 750 m. The rubber trees were spaced in rows at a distance of 4.5 to 5.0 m from each other. In contrast to the juvenile (3 year old) plantation, mature plantations (10 - 25 years) had canopy cover, horizontal root distribution and plantation floor covered with *Hevea* leaf litter. The floor of juvenile plantation had leguminous cover crop and grasses with scanty distribution of *Hevea* leaf litters.

Sampling of earthworm population: Sampling was done every month from June 2006 to May 2007. From each of the 5 plantations, an area of 1 ha was chosen within which 5 widely separated sampling plots 5 m×5 m were selected randomly. Five composite samples comprising of 25 sub-samples was taken from each of the five sampling plots every month. A total of 60 samples were taken for each age group of plantation during the study period. Earthworms were collected by the conventional digging (25×25×30 cm) and hand sorting method. Earthworms were weighed, counted, and a minimum of 10-15 worms of each species were preserved in 4% formalin and others were released back to the soil for conservation of biodiversity. Preserved specimens were sent to the Zoological Survey of India, Solan (Himachal Pradesh) for identification. Results were expressed in terms of biomass (fresh weight g individual^{-1}) and density (individuals m^{-2}). Using the data available, species richness index, Shanon diversity index, Simpson's index of dominance and species evenness (Dash and Dash, 2009) of earthworm communities were analyzed.

Soil analysis: Soil temperature (soil thermometer), soil moisture (gravimetric method) were recorded at each sampling site from a depth of 0 – 15 cm. Soil pH (1 : 2.5 water dilution method, systronics pH meter), organic carbon (rapid titration method, Walkley and Black, 1934) and nitrogen (Micro-Kjeldahl method) were determined.

Leaf chemical analysis : The rubber leaf litters (blades and petioles) from different age groups of plantations were collected. The leaf samples were oven-dried at 60°C and ground to pass a 0.5 mm mesh sieve. Using standard methods sugar (Miller, 1959), lignin (Zisheng *et al.,* 2007), polyphenol and flavonoid (Ghanta *et al.,* 2007) contents of *Hevea* leaves were determined. All extractions of *Hevea* litter were done in methanol with 1:10 (weight/ volume) ratio. Chemical analysis was done with two replicates from which the mean was calculated.

Data analysis : Variations in densities and biomasses of earthworms among different age groups of rubber plantations were tested by student's t-test. The relationship between population size (density and biomass) of earthworms and soil parameters were calculated as a simple correlation coefficient (r).

Results and Discussion

Site characteristics : Loamy sand soil (sand 78-88%, clay 5-15% and silt 6-11%) was the characteristics of 3 , 10 and 25-year-old plantations while both 14 and 20-year-old plantations had sandy soils (sand 86-90%, clay 4-7% and silt 5-7%). With increase in the size of the canopy, soil temperature gradually decreased from 27.14°C in 3-year-old plantation to 24.81°C in 25-year-old plantation and soil moisture gradually increased from 15.80% in 3-year-old plantation to 17.41% in 25-year-old plantation (Table 1). Organic matter and pH of soil did not show any definite trend with increase in the age of rubber plantation. Amount of over ground leaf litter and earthworm casts increased with plantation age (Table 1).

Community composition: Earthworms were concentrated mainly in the 0–15 cm of soil depth. Concentration of earthworms in the top soil was due to horizontal distribution of *Hevea* roots and slowly decomposing *Hevea* litters on the plantation floor that reflected better aerobic feeding cum breeding zone. A total of 12 earthworm species belonging to 9 genera and 5 families of the class oligochaeta were collected from rubber plantations of different age groups in the Taranagar Rubber Research Farm Area under Mohanpur block of West Tripura. Among them six species belonged to Octochaetidae [*Eutyphoeus assamensis* Stephenson, *Eutyphoeus comillahnus* Michaelsen, *Lennogaster chittagongensis* (Stephensen), *Octochaetona beatrix* Gates, *Dichogaster affinis* Michaelsen, *Lennogaster yeicus* (Stephensen)], two species each to Megascolecidae [*Metaphire houlleti* (Perrier), *Kanchuria* sp. 1] and Moniligastridae [*Drawida nepalensis* Michaelsen, *Drawida papillifer papillifer* Stephenson], one species each to Glossoscolecidae [*Pontoscolex corethrurus* (Muller)] and Ocnerodrilidae [*Gordiodrilus elegans* Beddard]. Exotic species *P. corethrurus, M. houlleti* and native peregrine species like *D. nepalensis* and *D. papillifer papillifer* were distributed in all the age groups of plantation, while other species showed restricted distribution. While the adults of *P. corethrurus* were found year round in the *Hevea* plantations, those of *M. houlleti* showed restricted period of activity during the monsoon and post monsoon period with their sudden disappearance in the month of November.

Table 1: A comparison between physico-chemical properties of the soils and biosynecological parameters of *Hevea brasiliensis* (rubber) plantations of different age groups in Taranagar area (Mohanpur Block, West Tripura)

Edaphic and Parameters	Different age groups of *Hevea* plantations				
	3 year	**10 year**	**14 year**	**20 year**	**25 year**
Soil texture	Loamy sand	Loamy sand	Sandy	Sandy	Loamy sand
Soil temperature (°C)	27.14 ± 0.55	25.08 ± 0.44	25.05 ± 0.53	24.87 ± 0.47	24.81 ± 0.49
Soil moisture (%)	15.80 ± 0.53	15.95 ± 0.55	16.20 ± 0.61	16.87 ± 0.51	17.41 ± 0.68
Soil pH	4.88 ± 0.08	4.58 ± 0.04	4.74 ± 0.07	4.78 ± 0.04	4.59 ± 0.01
Soil organic matter (g%)	1.75 ± 0.07	2.06 ± 0.12	1.28 ± 0.14	2.05 ± 0.15	1.80 ± 0.03
Total no. of earthworms collected (n = 60)	274	582	601	593	646
No. of species found	8	5	6	6	8
Litter biomass (g m^{-2})	2.8	200 - 700	750 - 1400	ND	800 - 1500
Worm casts (g m^{-2})	2	67	ND	75	84
Earthworm density (ind m^{-2})	35.33 ± 5.66	52.5 ± 13.4	67.75 ± 3.6	69.48 ± 5.68	82.53 ± 7.37
Earthworm biomass (g m^{-2})	10.8 ± 1.56	19.39 ± 2.63	35.54 ± 2.6	28.27 ± 2.3	32.8 ± 3.36
Species richness index (d)	0.84	0.29	0.48	0.50	0.53
Shannon diversity index (H)	1.95	1.09	1.34	1.35	1.34
Simpson's index of dominance (D)	0.15	0.41	0.37	0.33	0.33
Species evenness index (J)	0.94	0.68	0.75	0.75	0.64
Human interference	+	++++	++++	+++/++++	++

+ Little disturbance, ++ moderate disturbance, +++, ++++ high disturbance; ND – not determined

The activity of this litter feeding worm was certainly related to the stages of decomposition of rubber leaves. Interestingly, *M. houlleti* was found to be distributed in huge number in the over ground heaps of decomposed *Hevea* litters. Native earthworm species like *E. assamensis* and *E. comillahnus* while absent in 3 to 20 years plantations appeared in 25-year-old rubber plantation. Occurrence of *Eutyphoeus* sp. under climax forest was reported by Bhadauria and Saxena (2009). In the deciduous forests of Kentucky, occurrence of only native species in the undisturbed or slightly disturbed sites and exotic species in severely disturbed sites was reported by Kalisz and Dotson (1989). Rubber plantations often faces anthropogenic interferences like tapping process, forest cleaning etc. So occurrence of exotic species like *P. corethrurus* in the rubber plantation irrespective of age is not surprising. *P. corethrurus* being the commonest earthworm species of the world were also reported from rubber plantations of Malayasia, Burma, South India and China as well (Julka and Paliwal, 2005; Zhang *et al.,* 2010). It is possible that large scale introduction of Para rubber in the late 19th century into south-east Asia might have accelerated the expansion of its range (Shen and Yeo, 2005).

Inter-habitat variation in community characteristics : Numbers of earthworm species found in different habitats were eight in the 3-year-old plantation (*P. corethrurus, M. houlleti, D. nepalensis, D. papillifer papillifer, D. affinis, O. beatrix, L. chittagongensis, L. yeicus*), five in the 10-year-old plantation (*P. corethrurus, M. houlleti, D. nepalensis, D. papillifer papillifer, G. elegans*), six in the 14-year-old plantation (*P. corethrurus, M. houlleti, D. nepalensis, D. papillifer papillifer, E. assamensis, Kanchuria* sp. 1), six in the 20-year-old plantation (*P. corethrurus, M. houlleti, D. nepalensis, D. papillifer papillifer, G. elegans, Kanchuria* sp. 1) and eight in the 25-year-old plantation (*P. corethrurus, M. houlleti, D. nepalensis, D. papillifer papillifer, E. assamensis, D. affinis, L. chittagongensis, E. comillahnus*). Thus, present observation on the occurrence of 5 to 8 species of earthworms in the different age groups of plantation is well within the reported range of 4 to 14 earthworm species (Fragoso and Lavelle, 1995) for a given community (α diversity). Sudden decline in the number of earthworm species in 10 to 20-year-old plantation was probably due to rise in human interference in the form of latex harvesting, forest cleaning etc. After 20 years of rubber plantation, exploitation of rubber trees generally ends because of the decrease of latex yield (Gilot *et al.,* 1995; Zhang *et al.,* 2010). Thus, the number of species level to eight (as in 3 year old plantation) was restored at 25 year plantation.

Both the densities and biomasses of earthworms in general increased with increase in the age of rubber plantation (Table 1). Earthworm biomass and density in 14-year-old plantation is close to the values (biomass 34.2 to 42.4 g m^{-2}, density 68 m^{-2}) reported by Fragoso and Lavelle (1995) and Chaudhuri and Nath (2011). In the present study, *P. corethrurus* contributed more than 60% biomass and 70% density of earthworm community indicating biological invasion of this exotic species in rubber plantation (Nath and Chaudhuri, 2010).

Interestingly the biomass and density of earthworms increased with increase in surface litter biomasses in mature plantations compared to the juvenile plantation. Fragoso and Lavelle (1995) and Gonzalez *et al*.(1996) correlated an increase in abundance and fresh weight of earthworms with surface litter biomasses. High contents of polyphenol, flavonoid and lignin in the leaf litters of 3 and 10-year-old plantation (Fig. 1, 2) probably resulted to low biomass values of earthworms through their effects on food intake in those age groups of plantations. With further increase in the age of plantation beyond 10 years polyphenol, flavonoid and lignin contents decreased (Fig. 1, 2). Accordingly the biomass of earthworm increased with increase in the age of plantation. Highest biomass of earthworms (35.54 g m^{-2}) in 14-year-old plantation was due to highest level of sugar (soluble carbohydrate) and lowest level of polyphenol, flavonoid and lignin in *Hevea* litters of that age group of plantation (Table 1). Variation in the earthworm biomasses with changes in the content of polyphenol, flavonoid, sugar and lignin in the leaves of rubber plantation are shown in Fig. 1, 2.

Soil moisture and temperature act synergistically to influence earthworm activity (Edwards and Bohlen, 1996). Soil moisture increased from 15.80 to 17.41% and temperature decreased from 27.14 to 24.81°C with increase in age of rubber plantation from 3 to 25 years (Table 1). There was a good positive correlation between soil moisture and density and biomass of earthworms ($p<0.01$) (Fig. 3). Increase in the size of canopy cover (that cuts down direct radiation and minimizes evaporation) was probably responsible for gradual decline in the soil temperature and corresponding increase in the moisture content favouring building up of worm biomass and density with increase in the age of rubber plantation. According to Edwards and Bohlen (1996), soil moisture can influence the number and biomass of earthworms at any given location. Wood (1974) showed a strong positive correlation between earthworm biomass and increased soil moisture content for top soil inhabiting earthworm species in south-eastern Australia.

Increase in casting activities with increasing age of plantation (Table 1) was probably related to increase in shaded areas (provided by canopy) with improvement in soil moisture status. Remarkably low density and biomass

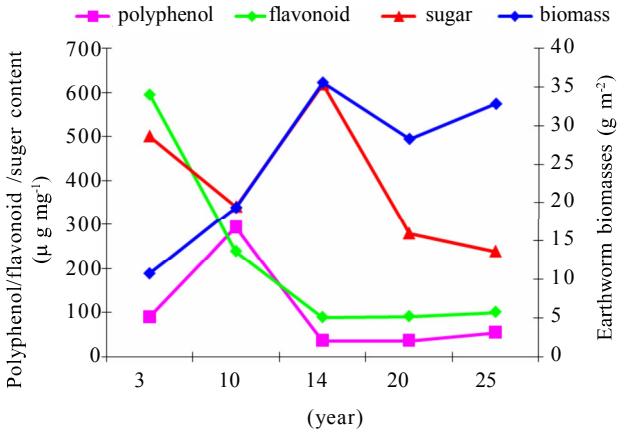

Fig. 1 : Variations in the earthworm biomasses with changes in polyphenol, flavonoid and sugar contents in the leaves of different age groups of *Hevea* plantations

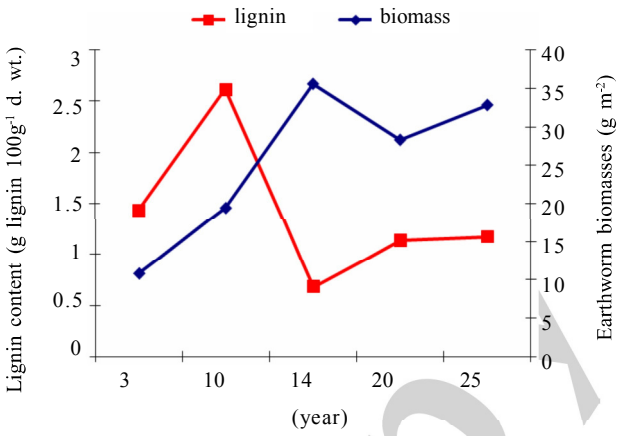

Fig. 2 : Variations in the earthworm biomasses with the changes in lignin content in the leaves of different age groups of *Hevea* plantations

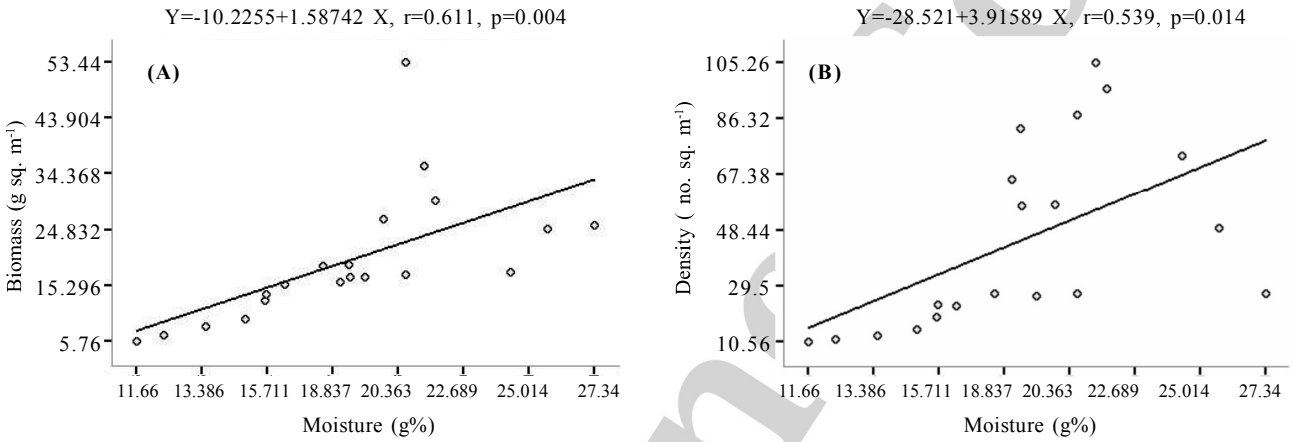

Fig. 3 : Relationship between (a) Earthworm biomass and soil moisture (b) Earthworm density and soil moisture

values and minimum casting activities of earthworms in 3-year-old plantation compared to mature plantations was probably due to its high temperature and low moisture content of the soil in absence of canopy cover in spite of the fact that here plantation floor was covered with leguminous plants to provide nitrogen to the soil.

It is probable that favourable temperature and moisture conditions along with litter quality and quantity with increasing plantation ages were responsible for providing suitable microclimate favouring gradual increase in population sizes of earthworms (Sanchez - Deleon *et al.,* 2003). Our observation corroborates with the study of Gillot *et al.* (1995) who also reported gradual increase in the density and biomass of earthworms in the rubber plantations of Cote d' Ivore with increase in the age of plantations. In Congo, Mboukou – Kimbatsa *et al.* (1998) and Bernhard – Reversat *et al.* (1999) reported on increase in termite, earthworm and litter group densities in *Eucalyptus* plantations of increasing age from 6 to 19 years. The increase in density of soil biota with plantation age suggests an improved soil functioning including rate of decomposition with age (Bernhard – Reversat and Loumeto, 2002).

In the 3-year-old plantation with least human disturbances, indices of the species diversity (1.95) and the species richness (0.84) were highest and the index of dominance (0.15) was lowest among different age groups of rubber plantation (Table 1). With sudden increase in human disturbances (viz. latex harvesting, forest clearing) in 10-year-old plantation, indices of the species diversity and the species richness became lowest (diversity 1.09, richness 0.29) and the dominance highest (0.41). With further increase in the age of rubber plantation beyond 10 years, lower indices of species diversity (1.34 to 1.35) and richness (0.48 to 0.53) and higher dominance (0.33 to 0.37) compared to that of

initial 3-year-old plantation were maintained (Table 1). In fact, highest species diversity in the 3-year-old plantation was due to highest number (eight) of species along with their more even distribution (evenness 0.94). In spite of having eight species of earthworms (similar to 3 year old plantation) in the 25-year-old plantation, species diversity (1.34) was less because here species were less evenly distributed (evenness 0.64) compared to that of 3-year-old plantation. Species diversity of earthworms in 10 to 25-year-old plantation was less than the reported range of 1.7 to 6.5 values for a given community (α diversity) in tropical rain forest (Fragoso and Lavelle, 1995) but that of 3-year-old plantation fall well within the reported range.

Higher dominance in the 10 to 25-year-old plantation was due to biological invasion of exotic species *P. corethrurus* in the rubber plantation. Following two factors mainly contributed to its invasion in rubber plantation: (i) anthropogenic disturbances that were tolerated well by exotic compared to endemic species (Kalisz and Wood, 1995; Chaudhuri *et al.,* 2009) and (ii) individual tree species affect that favored *P. corethrurus* over other earthworm species. Besides these wide range of tolerance to environmental factors, parthenogenic mode of reproduction, efficient assimilation of low quality soil organic matter and outstanding quality to colonize due to their demographic profile could explain the invasion of exotic earthworm, *P. corethrurus* in the tropics (Fragoso *et al.,* 1999; Gonzalez *et al.,* 2006; Nath and Chaudhuri, 2010; Chaudhuri and Bhattacharjee, 2011). Thus in the present study, density, biomass and dominance of earthworms increased, while species diversity, species richness and species evenness of earthworm communities decreased with increase in the age of rubber plantation.

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