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Community Characteristics of Earthworms in Different Age Groups of Pineapple Plantations (*Ananus comosus*) in West Tripura, India

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ABSTRACT

A total of 13 species of earthworms were collected from four age groups (0-5 years, 15-20 years, 30-35 years and 40-45 years) of pineapple plantations. Among them 4 species belonged to the family Megascolecidae [*Metaphire houlleti* (Perrier), *Metaphire posthuma* (Vailant), *Kanchuria* sp., *Kanchuria sumerianus* Julka], 5 species to the family Octochaetidae [*Eutyphoeus gigas* Stephenson, *Eutyphoeus scutarius* Michaelsen, *Eutyphoeus comillahnus* Michaelsen, *Eutyphoeus gammiei* (Beddard), *Eutyphoeus* sp.], 3 species to the family Moniligastridae [*Drawida assamensis* Gates, *Drawida papillifer papillifer* Stephenson, *Drawida nepalensis* Michaelsen] and one species to the family Glossoscolecidae [*Pontoscolex corethrurus* (Muller)]. Out of 13 species, only 5 [*Drawida assamensis*, *Drawida papillifer papillifer*, *Pontoscolex corethrurus*, *Metaphire houlleti* and *Eutyphoeus gigas*] were common to all the age groups of pineapple plantations. While *M. houlleti*, *M. posthuma* and *P. corethrurus* are exotic, the rest of the earthworm species are endemic to the Indian subcontinent. *D. assamensis* was the dominant earthworm species in all the age groups of pineapple plantation in respect of its density, biomass and relative abundance. While 30-35 years old pineapple plantation showed highest species richness (as indicated by presence of 11 earthworm species) the other age groups of plantations had only 7-8 earthworm species. The overall earthworm densities and biomasses increased significantly ($P < 0.01$) with increase in the age of pineapple plantation. A significant decrease ($P < 0.05$) in Shannon diversity index and species evenness and significant increase ($P < 0.05$) in Simpson's dominance index with increase in the age of plantation was worthy of note.

Keywords: earthworm diversity, monoculture, pineapple plantation, plantation age, species richness

INTRODUCTION

Pineapple (*Ananas comosus* (L.) Merr.) native to the Southern Brazil and Paraguay was introduced to India by Portuguese in 1548 A.D. (Bartholomew *et al.* 2003). It is one of the most delicious tropical fruit crops of commercial importance and widely cultivated in the hill slopes of Tripura, checking soil erosion. Pineapple – the only edible fruit crop of Bromeliaceae, is herbaceous, hardy with weak root system and good draught tolerant due to its high stomatal resistance (Kole 2011). It is perennial that usually flowers from February to April. Reproduction is exclusively through vegetative propagules. Fruits are harvested during mid May to mid July. Crude extracts from fruits, stem and leaves of pineapple are good sources of various kinds of sugars, organic acids, vitamins and several proteinase enzymes including bromelains and peroxidases with immunomodulatory, anti-inflammatory, antithrombotic, fibrinolytic, antihelminthic and tumour growth inhibitory property (Ghosh *et al.* 2008; Kole 2011). The agro-climatic conditions prevailing in Tripura is ideal for commercial production of its three common varieties viz. Queen, Kew and Mauritius.

Direct effect of plant species on soil organisms are caused by the plant's inputs of organic matter above and below ground, while indirect effect of plants on biota include shading, soil protection and uptake of water and nutrients by roots (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. According to Bernhard-Reversat and Loumeto (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, flavonoid and polyphenol contents of plant with increase in plot age was reported by Howell *et al.* (1976), Arunachalam *et al.* (1996) and Chaudhuri *et al.* (2013). 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 earthworm population. 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 and production (Kavdir 2011; Chaudhuri *et al.* 2012). Monoculture practices always lead to dominance and decrease in biodiversity (Chaudhuri and Nath 2011; Dey *et al.* 2012). Interestingly Nath and Chaudhuri (2010) reported human induced biological invasion of exotic earthworm *Pontoscolex corethrurus* in monoculture rubber plantation.

In fact, reports are scanty on the effect of the age of plantation on soil biota (Chaudhuri *et al.* 2013). Therefore we undertook this study to describe changes if any in community structure, species diversity and dominance of earthworms with increasing age of pineapple plantation.

MATERIALS AND METHODS

Study area and sites

The studies on the earthworm communities were conducted during April 2008 – September 2011 in the pineapple plantations (queen variety) of four different age groups: 1-5 years old, 15-20 years

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old, 30-35 years old and 40-45 years old plantations in Tripura having a total area of 10,491 sq. km. The state is almost encircled by Bangladesh except in the north-east where it meets its neighbouring states, Assam and Mizoram. For each age group of plantation, 3 replicates were taken. Sampling of earthworms were done at different localities viz. Bamutia, Nandannagar, Shalbagan, Nutannagar, Bishalgarh, Bishramganj, Padmanagar, Jumerdhepa and Boiragibazar of west Tripura. The distance between the studied sites varied from 20-50 km.

Pineapple cannot tolerate water logged condition and are thus usually on undulating uplands, locally called tilla. The soils of well drained pineapple plantations were acidic (pH 4.6-5.5) in nature with loamy sand, loam or sandy loam texture. *Nephelium litche* (Sapindaceae) was the most abundant tree common to all age groups of pineapple plantation. Besides this, presence of *Mangifera indica* (Anacardiaceae) and *Casia tora* (Caesalpinaceae) in 15-20 years plantation, *Syzygium cumini* (Myrtaceae) and *Casia sophera* (Caesalpinaceae) in both 30-35 years and 40-45 years pineapple plantations were remarkable. A few juvenile plants of *Nephelium litche* and *Mangifera indica* were scatteredly distributed in 1-5 years plantation.

The year is divisible into summer (March-May), monsoon (June-September), autumn (October-November) and winter (December-February). The study areas experienced a tropical climate with a mean annual rainfall of 2000 mm and temperature of 25°C.

Earthworm sampling

Earthworms were collected during periods of earthworm activity i.e. from June to October of 2008-2011 by conventional digging and hand sorting (25 cm × 25 cm × 25 cm) (Dey *et al.* 2012). In each of the replicated study plots (three in number) under different age groups of pineapple plantations, 100 samples were taken from a generally plain terrain of 150 × 150 m^2 along transects with random origin. Each transect passed in between the rows of pineapple plantations. The distance between the neighbouring plants and two rows of pineapples were 30 and 60 cm, respectively. A total of 300 samples were taken from each of the age group of plantations. Earthworms were only collected from the plain plots above and below the stiff slopes due to the difficulties of sampling in the latter. In the field, earthworms were counted and weighed on a electronic balance. Results were expressed in terms of biomass (fresh weight g m^{-2}) and density (ind. m^{-2}). Using the data available, relative abundance, frequency, index of dominance (Simpson 1949), species richness index (Menhinick 1964), index of general diversity (Shannon and Weaner 1963), species evenness (Dash and Dash 2009) of earthworm communities of the studied sites were determined. Morisita's index of dispersion (I_d) (Morisita 1959) for quadrate count of earthworms was employed to find out the horizontal distribution pattern of earthworms in different age groups of pineapple plantations. I_d will give expected values <1 and >1 for uniform and clumped distribution, respectively.

Sample data of all species collected during the study period from the four age groups of pineapple plantations were pooled to create species accumulation curve for determining sampling efficiency i.e. a plot with a number of species as a function of the number of individuals sampled (Sorensen *et al.* 2002). Raw data on species richness counts during the study period from each of the age group of pineapple plantations were pooled to provide rarefaction curves (Unterseher *et al.* 2008) for comparing estimated species richness among the four age groups of plantations. Steeper curves indicate more diverse communities. To determine the abundance pattern of the earthworm species, the rank abundance curve (Ramesh *et al.* 2010) was plotted using overall relative abundance of each species in the four types of studied sites. The common species are displayed on the left and rare species on the right side of the curve plotted for the earthworm species of four types of plantations.

Soil analysis

Soil samples were dug from 0–15 cm depth. Composite soil samples comprising of 5 sub-samples were prepared for physico-chemical analysis. Soil samples were air dried, ground with mortar and pestle and sieved with 1 mm and 2 mm sieves. Soil samples were analysed for their moisture (gravimetric wet weight method), pH (1: 2.5 dilution method), soil organic matter (Walkley and Black 1934) and hand texture method (Daji 1996). Soil temperature was recorded in-situ at each sample plot at a depth of 15 cm.

Data analysis

Variations in physico-chemical properties of soil and some biological parameters like earthworm density and biomass among the four studied sites 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 significantly different, at 5% level of significance. A univariate ANOVA was carried out separately by using earthworm density and biomass as dependent (response) and age group of plantation as independent variable (predictor) (Montgomery *et al.* 2007) to assess the influence of vegetation age on earthworms and whether it is significant or not (Santos *et al.* 2010; Potvin *et al.* 2011). Difference among the species indices data viz. index diversity, index of dominance, index of evenness, species richness index and Morisita's index were tested non-parametrically by using Kruskal-Wallis analysis of variance (Kruskal and Wallis 1952) followed by Wilcoxon-Mann-Whitney test (Wilcoxon 1945; Mann and Whitney 1947) for pair wise comparisons. The nature of relationship between soil parameters viz. temperature, moisture, pH, organic matter and earthworm population density and biomass were calculated as simple regression co-efficient (r) (Zar 1999; Pagano and Gauvreau 2004). Similarities of earthworm species composition in four age groups of pineapple plantations were identified using single link cluster analysis based on Bray-Curtis similarity (McAleece 1998).

RESULTS

Site characteristics

Pineapple plantations of 1-5 years and 15-20 years age groups had loamy sand and loam soils, while both 30-35 years and 40-45 years age groups had sandy loam soils respectively. In all the studied sites earthworm species were mostly distributed within 15 cm soil depth. Temperature, moisture, pH, organic matter differed significantly ($P < 0.01$) among the different age groups of pineapple plantations (**Table 1**). According to Tukey's post-hoc test all the soil parameters of the four different age group of plantations were significantly ($P < 0.05$) different from each other also.

Community composition

A total of 13 species of earthworms were collected from the four age groups of pineapple plantation. Among them 4 species belonged to the family Megascolecidae [*Metaphire houlleti* (Perrier), *Metaphire posthuma* (Vailant), *Kanchuria* sp., *Kanchuria sumerianus* Julka], 5 species to the family Octochaetidae [*Eutyphoeus gigas* Stephenson, *Eutyphoeus scutarius* Michaelsen, *Eutyphoeus comillahnus* Michaelsen, *Eutyphoeus gammiei* (Beddard), *Eutyphoeus* sp.], 3 species to the family Moniligastridae [*Drawida assamensis* Gates, *Drawida papillifer papillifer* Stephenson, *Drawida nepalensis* Michaelsen] and one species to the family Glossoscolecidae [*Pontoscolex corethrurus* (Muller)]. Out of 13 species, only 5 species [*Drawida assamensis*, *Drawida papillifer papillifer*, *Pontoscolex corethrurus*, *Metaphire houlleti* and *Eutyphoeus gigas*] were common to all the age groups of pineapple plantations (**Table 2**). *M. houlleti*, *M. posthuma* and *P. corethrurus* are exotic, whereas the rests are endemic to the Indian subcontinent. Density, biomass and relative abundance of different earthworm species are shown in **Table 2**. In respect of their density, biomass and relative abundance, *D. assamensis* was the dominant earthworm species and *M. posthuma*, *Kanchuria* sp., *K. sumerianus*, *E. gigas*, *E. scutarius*, *E. comillahnus*, *E. gammiei*, *Eutyphoeus* sp. and *D. nepalensis* were the rare species

Table 1 Physico-chemical properties of soil and biosynecological parameters of 4 pineapple plantations of different age group.

Parameters*	1-5 years	15-20 years	30-35 years	40-45 years	F value	P value
Soil texture	Loamy sand	Loam	Sandy loam	Sandy loam		
Temperature (^{O}C	26.62 ± 0.07a	26.14 ± 0.07b	25.83 ± 0.07c	25.45 ± 0.07d	45.68	<0.01
Moisture (%)	16.61 ± 0.29a	18.84 ± 0.43b	20.09 ± 0.35c	22.33 ± 0.30d	47.45	<0.01
pH	5.02 ± 0.04a	4.81 ± 0.33b	4.63 ± 0.04c	4.25 ± 0.02d	92.41	<0.01
Oxidizable carbon (%)	0.79 ± 0.01a	0.99 ± 0.06b	1.38 ± 0.03c	1.45 ± 0.03c	69.35	<0.01
Organic matter (%)	1.36 ± 0.02a	1.93 ± 0.08b	2.38 ± 0.06c	2.48 ± 0.06c	77.99	<0.01
Worm density (ind./m^2)	53.73 ± 2.57a	77.2 ± 2.89b	158.67 ± 8.17c	191.07 ± 2.24d	196.32	<0.01
Worm biomass (g/m^2)	15.04 ± 1.83a	23.78 ± 2.06b	41.92 ± 0.67c	45.66 ± 3.19c	46.85	<0.01
Species richness	7	7	11	8		
Diversity indices**	**1-5 years**	**15-20 years**	**30-35 years**	**40-45 years**	**H value**	**P value**
Shannon_H	1.24 ± 0.04a	0.92 ± 0.02b	0.67 ± 0.06c	0.61 ± 0.03c	9.67	<0.05
Dominance_D	0.35 ± 0.01a	0.54 ± 0.02b	0.69 ± 0.02c	0.72 ± 0.01c	9.66	<0.05
Evenness index	0.71 ± 0.06a	0.43 ± 0.05b	0.28 ± 0.04c	0.27 ± 0.01c	9.46	<0.05
Species richness index	0.43 ± 0.04a	0.43 ± 0.05a	0.37 ± 0.05ac	0.31 ± 0.02bc	5.67	>0.05
Morisita's index	1.15 ± 0.02a	1.28 ± 0.047b	1.2 ± 0.02ab	1.05 ± 0.03c	9.22	<0.05

Values represent mean ± standard error (SE); Dissimilar letters indicate significant difference at 5% level of significance
*One-way ANOVA, **Kruskal-Wallis test

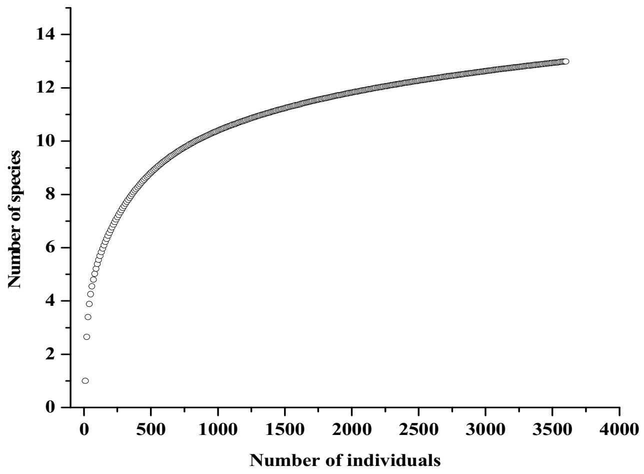

Fig. 1 Species accumulation curve for earthworm species in pineapple plantations.

(**Table 2**) of pineapple plantations. *M. houlleti* and *D. papillifer papillifer* were the only epianecic (phytogeophagus) worms found in pineapple plantations, whereas the remaining species were endogeic (geophagus). Species accumulation curve showed an initial steep slope for samples of about 400 individuals followed by a gentle rise to reach a near saturation of species richness at overall abundance between 2800 and 3200 earthworms (**Fig. 1**).

Inter-habitat variations in community characteristics

The survey showed varied number of earthworm species (species richness) in different habitats: seven species in 1-5 year age group (viz. *D. assamensis*, *P. corethrurus*, *D. papillifer papillifer*, *E. gigas*, *M. houlleti*, *M. posthuma* and *E. gammiei*), seven in the 15-20 years age group (viz. *D. assamensis*, *P. corethrurus*, *D. papillifer papillifer*, *E. gigas*, *M. houlleti*, *Eutyphoeus* sp. and *Kanchuria* sp.), eleven in the 30-35 years age group (viz. *D. assamensis*, *P. corethrurus*, *D. papillifer papillifer*, *E. gigas*, *M. houlleti*, *Eutyphoeus* sp., *Kanchuria* sp., *E. comillahnus*, *D. nepalensis*, *E. scutarius* and *K. sumerianus*) and eight species in the 40-45 years age group of plantations (viz. *D. assamensis*, *P. corethrurus*, *D. papillifer*, *D. nepalensis*, *E. gigas*, *M. houlleti*, *Kanchuria* sp. and *E. comillahnus*).

Cluster analysis based on Bray-Curtis single linkage similarity value revealed the percent similarity between earthworm species composition across the four pineapple plantation types. The dendrogram obtained by clustering of four age groups of pineapple plantations divided all sites in two distinct categories A and B (**Fig. 2A**). Category A comprised of less aged plantations (1-5 and 15-20 year plantations) and the category B of old plantations (30-35 and 40-45 year plantations). Both the clusters were subdivided into individual plantations with definite age group (**Fig. 2A**). The categories, A and B showed linkage at 64.93% (which represent lowest) similarity. The similarity between 1-5 and 15-20 year plantations was 73.6%, while 30-35 and 40-45 year plantations were liked at 89.13% similarity. The similarity matrix of four age groups of pineapple plantations revealed that with increase in plantation age, pair-wise inter-habitat percentage of similarity decreased gradually (**Fig. 2B**).

The species richness index was highest in 30-35 years old plantation, while in the other age groups of plantation it varied from 7 to 8 (**Table 1**). Rarefaction curves from the four age groups of plantations initially showed a sharp rise (up to 5 species level) and approached towards asymptote gently in 1-5 year, 15-20 years and 30-35 years age groups of plantation (**Fig. 3**). Steepness of the rarefaction curve was highest in the 30-35 years old and lowest in the 15-20 years old plantation (**Fig. 3**).

The overall earthworm densities and biomasses differed significantly ($P < 0.01$) among different age groups of pineapple plantations. There was an increasing trend in overall biomasses and densities of earthworms with increase in plantation age (**Table 1**). The analysis of univariate ANOVA confirms the fact by showing significant ($P < 0.01$) influence of pineapple plantation age on earthworm population densities (F=208.69, R^2=0.57) and biomasses (F=47.29, R^2=0.23). Maximum earthworm density (191 ind m^{-2}) and biomass (45 g m^{-2}) were recorded in 40-45 year old pineapple plantation. Earthworm population densities and biomasses differed significantly ($P < 0.05$) among different age groups of plantation except those in between 40-45 year and 30-35 year age groups of plantation. The overall mean densities and biomasses of earthworms in the pineapple plantation were 120.17±32.62 ind m^{-2} and 31.6±7.30 g m^{-2}, respectively. Near absence of some rare earthworm species viz. *Eutyphoeus* sp, *E. comillahnus*, *D. nepalensis* and *E. scutarius* in young pineapple plantations (**Table 2; Fig. 5**) were noteworthy. Among the five common earthworm species of pineapple plantations, the density and biomass percent of *D. assamensis* gradually increased, whereas those of the others decreased with increase in age of the pineapple plantation (**Fig. 4**). Interestingly in 40-45 years old pineapple plantation, both densities and biomasses of *D. assamensis* accounted for more than 80% densities and biomasses of all other earthworm species.

Relative abundance of *D. assamensis* increased significantly ($P < 0.01$) from 48% in 1-5 year age group of plantation to 70% in 15-20 year old plantation and 82% in the 30-35 year old plantation (**Table 2**). In the rank abundance curve, *D. assamensis* occupied the highest position followed by a few moderately abundant and large proportions

Table 2 Density, biomass, relative abundance and frequency of earthworm species in different age groups of pineapple plantation

Family and earthworm species	Age group	Biomass (g m^{-2})	Density (ind. m^{-2})	Relative abundance (%)	Frequency (%)
Megascolecidae					
*M. houlleti**	1-5 yr	1.25 ± 0.06	4.53 ± 0.27	8.52 ± 0.86	20 ± 1.44
	15-20 yr	0.58 ± 0.19	3.33 ± 0.81	4.25 ± 0.89	15 ± 2.89
	30-35 yr	1.64 ± 0.50	3.07 ± 0.87	1.89 ± 0.43	13.33 ± 4.64
	40-45 yr	1.04 ± 0.09	4.40 ± 0.61	2.08 ± 0.13	15.83 ± 2.21
*M. posthuma**	1-5 yr	0.17 ± 0.01	0.53 ± 0.05	0.91 ± 0.09	1.67 ± 1.07
	15-20 yr	0	0	0	0
	30-35 yr	0	0	0	0
	40-45 yr	0	0	0	0
Kanchuria sp.	1-5 yr	0	0	0	0
	15-20 yr	0.08 ± 0.08	0.27 ± 0.13	0.36 ± 0.18	1.67 ± 0.83
	30-35 yr	0.62 ± 0.09	1.20 ± 0.46	0.76 ± 0.30	3.33 ± 0.83
	40-45 yr	0.15 ± 0.08	0.67 ± 0.35	0.35 ± 0.18	3.33 ± 1.67
K. sumerianus	1-5 yr	0	0	0	0
	15-20 yr	0	0	0	0
	30-35 yr	0.15 ± 0.05	0.13 ± 0.03	0.08 ± 0.01	0.83 ± 0.03
	40-45 yr	0	0	0	0
Octochaetidae					
E. gigas	1-5 yr	0.09 ± 0.03	0.4 ± 0.04	0.77 ± 0.07	1.67 ± 1.07
	15-20 yr	0.89 ± 0.26	0.67 ± 0.13	0.85 ± 0.15	3.33 ± 0.83
	30-35 yr	1.11 ± 0.01	0.27 ± 0.02	0.17 ± 0.02	1.67 ± 0.02
	40-45 yr	0.17 ± 0.09	0.67 ± 0.35	0.35 ± 0.19	3.33 ± 1.67
E. scutarius	1-5 yr	0	0	0	0
	15-20 yr	0	0	0	0
	30-35 yr	0.30 ± 0.03	0.27 ± 0.02	0.15 ± 0.01	1.67 ± 0.05
	40-45 yr	0	0	0	0
E. comillahnus	1-5 yr	0	0	0	0
	15-20 yr	0	0	0	0
	30-35 yr	0.63 ± 0.06	0.40 ± 0.04	0.26 ± 0.01	1.67 ± 0.07
	40-45 yr	0.18 ± 0.09	0.80 ± 0.46	0.43 ± 0.25	4.17 ± 2.21
Eutyphoeus sp.	1-5 yr	0	0	0	0
	15-20 yr	0.11 ± 0.11	0.27 ± 0.02	0.35 ± 0.04	1.67 ± 1.06
	30-35 yr	0.16 ± 0.01	0.27 ± 0.07	0.15 ± 0.05	1.67 ± 0.05
	40-45 yr	0	0	0	0
E. gammiei	1-5 yr	0.04 ± 0.03	0.13 ± 0.01	0.23 ± 0.02	0.83 ± 0.08
	15-20 yr	0	0	0	0
	30-35 yr	0	0	0	0
	40-45 yr	0	0	0	0
Moniligastridae					
D. assamensis	1-5 yr	7.34 ± 1.01	26.13 ± 1.50	48.65 ± 1.80	60 ± 2.89
	15-20 yr	15.12 ± 0.51	54.40 ± 1.41	70.56 ± 1.61	95 ± 2.88
	30-35 yr	28.16 ± 0.39	130.93 ± 4.96	82.63 ± 1.12	95.83 ± 3.01
	40-45 yr	38.58 ± 2.7	161.47 ± 2.91	84.50 ± 0.65	100 ± 0.00
D. papillifer papillifer	1-5 yr	1.76 ± 0.26	6.27 ± 0.48	11.63 ± 0.33	30 ± 2.89
	15-20 yr	0.85 ± 0.22	4.53 ± 0.27	6.04 ± 0.59	17.5 ± 2.5
	30-35 yr	2.36 ± 0.48	4.93 ± 0.93	3.07 ± 0.41	21.67 ± 4.17
	40-45 yr	0.78 ± 0.03	3.33 ± 0.35	1.75 ± 0.20	14.17 ± 2.21
D. nepalensis	1-5 yr	0	0	0	0
	15-20 yr	0	0	0	0
	30-35 yr	0.44 ± 0.22	0.67 ± 0.35	0.40 ± 0.21	2.5 ± 1.44
	40-45 yr	0.31 ± 0.16	1.33 ± 0.71	0.70 ± 0.38	4.17 ± 2.21
Glossoscolecidae					
*P. corithrurus**	1-5 yr	4.38 ± 0.45	15.73 ± 0.87	29.30 ± 1.14	55 ± 3.82
	15-20 yr	6.04 ± 1.04	13.73 ± 1.87	17.72 ± 1.98	59.17 ± 3.01
	30-35 yr	6.35 ± 2.27	16.53 ± 0.93	10.44 ± 0.48	74.17 ± 7.12
	40-45 yr	4.44 ± 0.63	18.4 ± 1.51	9.62 ± 0.72	83.33 ± 6.82

Values represent mean ± standard error (SE); *exotic species

of rare species of earthworms (**Fig. 5**).

A significant decrease ($P < 0.05$) in Shannon diversity index and species evenness and significant increase ($P < 0.05$) in Simpson's dominance index with increase in the age of pineapple plantation up to 30-35 years old plantation was noted. However, there was no significant change ($P > 0.05$) in Shannon diversity index, species evenness and Simpson's dominance index with further increase in the age of pineapple plantation as revealed by Wilcoxon-Mann-Whitney test.

The Morisita's index of dispersion (I_d) was greater than 1 in all the age groups of pineapple plantation (**Table 1**) that reveals the aggregated nature spatial distribution of earthworm communities. Highest value (1.28) of I_d in 15-20 year age group of plantation indicates the highest degree of clumping. A gradual decrease in the in the degree of clumping in 30-35 and 40-45 years age groups of plantation was remarkable.

Earthworms / soil properties relationship

Soil temperature and moisture of the studied sites showed a significant ($P < 0.01$) negative and positive correlation with overall earthworm biomass and density respectively (**Fig. 6A-D**). Soil organic matter also showed a significant ($P < 0.01$) positive correlation with earthworm density (**Fig. 6E**). Although earthworm population in general showed insignificant correlation ($P > 0.05$) with pH, density and biomass

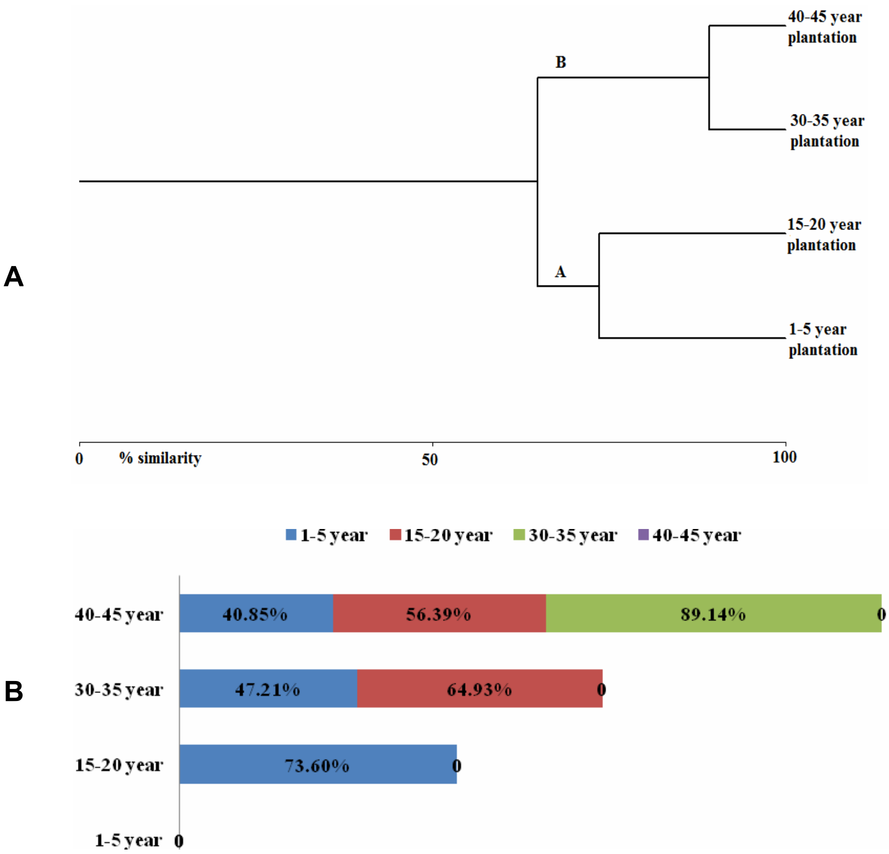

Fig. 2 (**A**) Single linkage cluster analysis and (**B**) inter-habitat similarity matrix showing individual pair-wise percentage of similarity between different age groups of pineapple plantations.

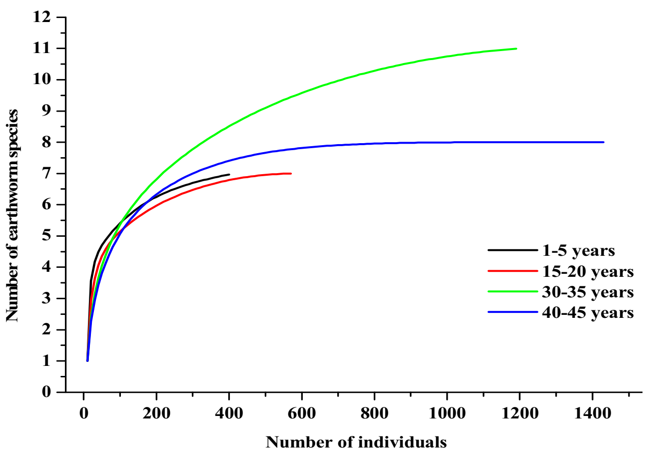

Fig. 3 Rarefaction curves for the four different age groups of pineapple plantations.

of *D. assamensis* showed significant ($P < 0.01$) negative correlation with pH (**Fig. 6F, 6G**).

DISCUSSION

A minimum of seven (1-5 year old and 15-20 year old plantation) and a maximum of eleven (30-35 year old plantation) earthworm species are distributed in the studied sites among the 13 earthworm species found during the survey. This is well within the reported range of 4 to 14 species (mean species richness 6.5±1.3 species) in the earthworm communities of tropical rain forest (Edwards and Bohlen 1996). The nature of steepness and non attainment of asymptote of species accumulation curve is indicative of underestimate of the true species richness (Coddington *et al.* 1996) of the study sites which is evident by occurrence of a good number of rare species of earthworms in the pineapple

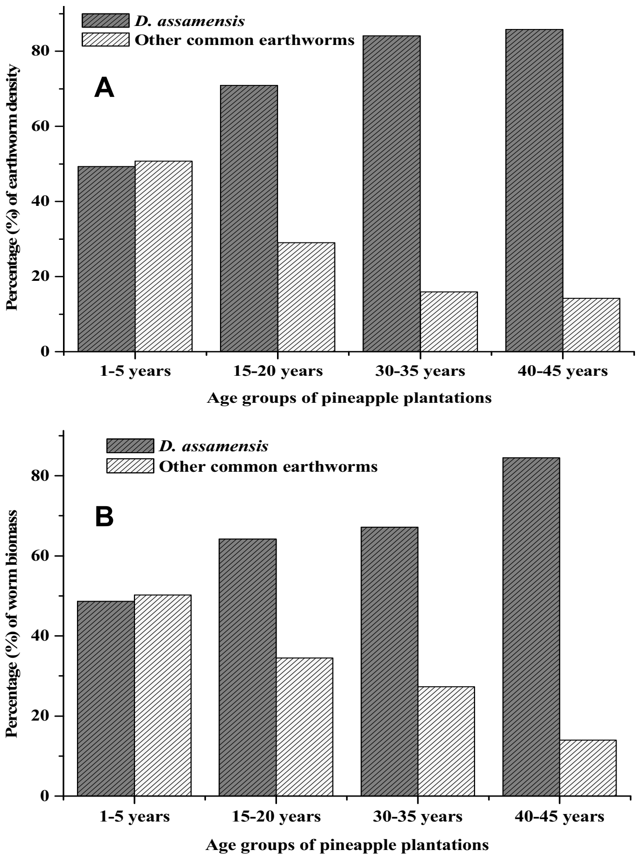

Fig. 4 (**A**) Density (%) and (**B**) biomass (%) values of *Drawida assamensis* and other four common earthworm species in different age groups of pineapple plantations compared.

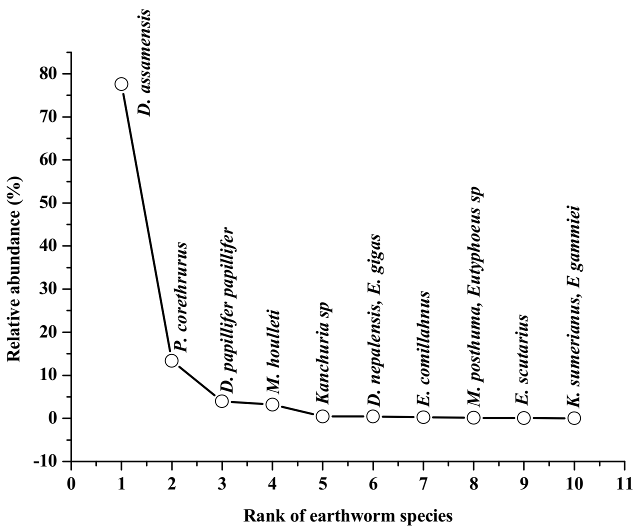

Fig. 5 Overall species rank abundance of earthworms from different age groups of pineapple plantations.

plantations (Unterseher *et al.* 2008). Since short term sampling does not cover all the species which are active at different seasons of a year, the actual number of species estimated for the pineapple plantations of west Tripura might be higher than the present predicted value. Occurrence of 5 earthworm species in pineapple plantations in east Khasi hills of Meghalaya was reported by Tiwari *et al.* (1992). Less species richness in the pineapple plantations of east Khasi hills compared to our present observation is probably linked with altitude effect on faunal diversity (Palin *et al.* 2011). The difference in the species composition in the earthworm communities among the different studied age groups of pineapple plantations of west Tripura indicates the importance of habitat heterogeneity (β-diversity) in the diversity of earthworms as shown by Fragoso and Lavelle (1987) in the forests of Mexico. The steeper rarefaction curve observed for 30-35 years age group of plantation supports the occurrence of maximum number of species (11 species) including some less abundant or rare species of earthworms like *K. sumerianus*, *Kanchuria* sp, *E. scutarius*, *E. comillahnus*, *E. gigas* and *D. nepalensis* in comparison to all other age groups of plantations. In fact, species richness estimates were highly influenced by rare species. The larger the number of rare species, the greater would be the difference between observed and the true species richness for the assemblages sampled (Dey *et al.* 2012).

Cluster analysis showed that approximately 65% of the total earthworm species recorded during the sampling in all plantation types was same despite of differences in habitat characteristics. Study conducted by Dey and Chaudhuri (2012) in two age groups of pineapple plantations also showed low beta diversity of earthworms. High similarity value of earthworm fauna between different age groups of pineapple plantation is the indication of low beta diversity and availability of more or less similar niches in each of the studied plantation. This fact corroborates Chaudhuri *et al.* (2013) and Nath and Chaudhuri (2010) who also found similar facts in the different age groups of rubber plantations of Tripura.

A clear increasing trend in average biomasses and densities of earthworms with the increase in the age of pineapple plantation corroborates with the study of Gillot *et al.* (1995) and Chaudhuri and Bhattacharjee (2009), who also reported gradual increase in earthworm densities and biomasses in rubber plantations with increase in age of plantations. Significant increase in the earthworm density associated with the increasing age of *Eucalyptus* plantations was noticed by Mboukou-Kimbatsa and Bernhard-Reversat (2001). The mean earthworm densities (120.17±32.62 ind m^{-2}) and biomasses (31.6±7.30 g m^{-2}) in pineapple plantations of Tripura are comparable to those of the tropical rain forest (Fragoso and Lavelle 1987; Leaky and Proctor 1987), natural forest and *Acacia* plantation (Blanchart and Julka 1997), rubber plantation (Chaudhuri *et al.* 2008). A four folds increase in densities and three folds increase in biomasses of earthworms in the 40-45 year age group plantation compared with the 1-5 year old plantation was probably due to a significant increase ($P < 0.01$) in soil organic carbon and soil moisture and significant decrease ($P < 0.01$) in temperature with increasing plantation age (Edwards and Bohlen 1996). Decaenas (2003) proposed that increased faunal activity with the aging of plots was due to availability of trophic resource (i.e. dead roots, decomposed leaves) that sustained a high carrying capacity.

D. assamensis was the only dominant species in all of our studied age groups of pineapple plantations in respect of its biomass, density, frequency and relative abundance. Tiwari *et al.* (1992) also reported *D. assamensis* as a dominant earthworm species in pineapple plantations in the east Khasi hills of Meghalaya. This is a reflection of a situation where one or a few factors dominate the ecology of a community (Magurann 1988). Factors contributing to the dominance in pineapple plantation may be individual plant species effect (Sarlo 2006) that favoured *D. assamensis* over other species of earthworms in addition to the competitive interaction with other earthworm species of pineapple plantations. The latter is important because density and biomass percent of *D. assamensis* increased and those of other earthworm species decreased with increase in plantation age. Recently, Chaudhuri *et al.* (2008) and Nath and Chaudhuri (2010) reported dominance of *P. corethrurus* and its invasion in man-made agro-ecosystems like rubber plantation. The highest rank of *D. assamensis* in the rank abundance curve reveals its survival superiority over other earthworm species of pineapple plantation.

The gradual decrease in the indices of Shannon diversity together with an increase in dominance is probably linked with the dramatic increase in the population density of dominant earthworm *D. assamensis* in pineapple plantations with increase in their age. According to Shakir and Dindal (1997), population density is negatively correlated with species diversity. These authors reiterated that the lower population density for the rare species were linked to high diversity and highest population densities for dominant species correlated with lower diversity. Thus lower population densities of rare octochaetid species such as *E. gigas*, *E. comillahnus* and *E. scutarius* in young plantations (1-5 year old) and higher population densities of dominant earthworm species, *D. assamensis* in aged plantations (30-35 year and 40-45 years old) were correlated with higher diversity in the former and lower diversity in the latter. In spite of higher species richness (11 species) in 30-35 year old plantation its diversity was lower compared to young plantations having a smaller number of species (7 species) due to dramatic increase in the densities of dominant species, *D. assamensis* in the former. Highest population density (191 ind m^{-2}) of dominant species, *D. assamensis* in 40-45 years old plantation attributed to its lowest diversity. According to Fragoso and Lavelle (1992) species diversity of earthworms in tropical rain forests ranges from 1.7 to 6.5. Thus species diversity of earthworms in pineapple plantation (0.61-1.24) is much less than that of tropical rain forest (3.6), natural forests in western ghat (2.5) and mixed forest (1.76) of Tripura (Fragoso and Lavelle 1992; Blanchart and Julka 1997; Chaudhuri and Nath 2011) but similar to that of monoculture rubber plantation (0.86) (Chaudhuri and Nath 2011).

Spatially clumped distribution of earthworm communities in the four age groups of pineapple plantation corroborates Sileshi (2008), who also observed the spatially distributed clusters within earthworm communities in the agroforestry assemblages of Mimbo, Eastern Zambia. Patchiness at spatial level of earthworm populations was also reported by several other authors in tropics (Rossi and Lavelle 1998; Gonzalez *et al.* 1999; Jimenez *et al.* 2001; Rossi 2003; Martinez *et al.* 2006; Rossi *et al.* 2006) and under

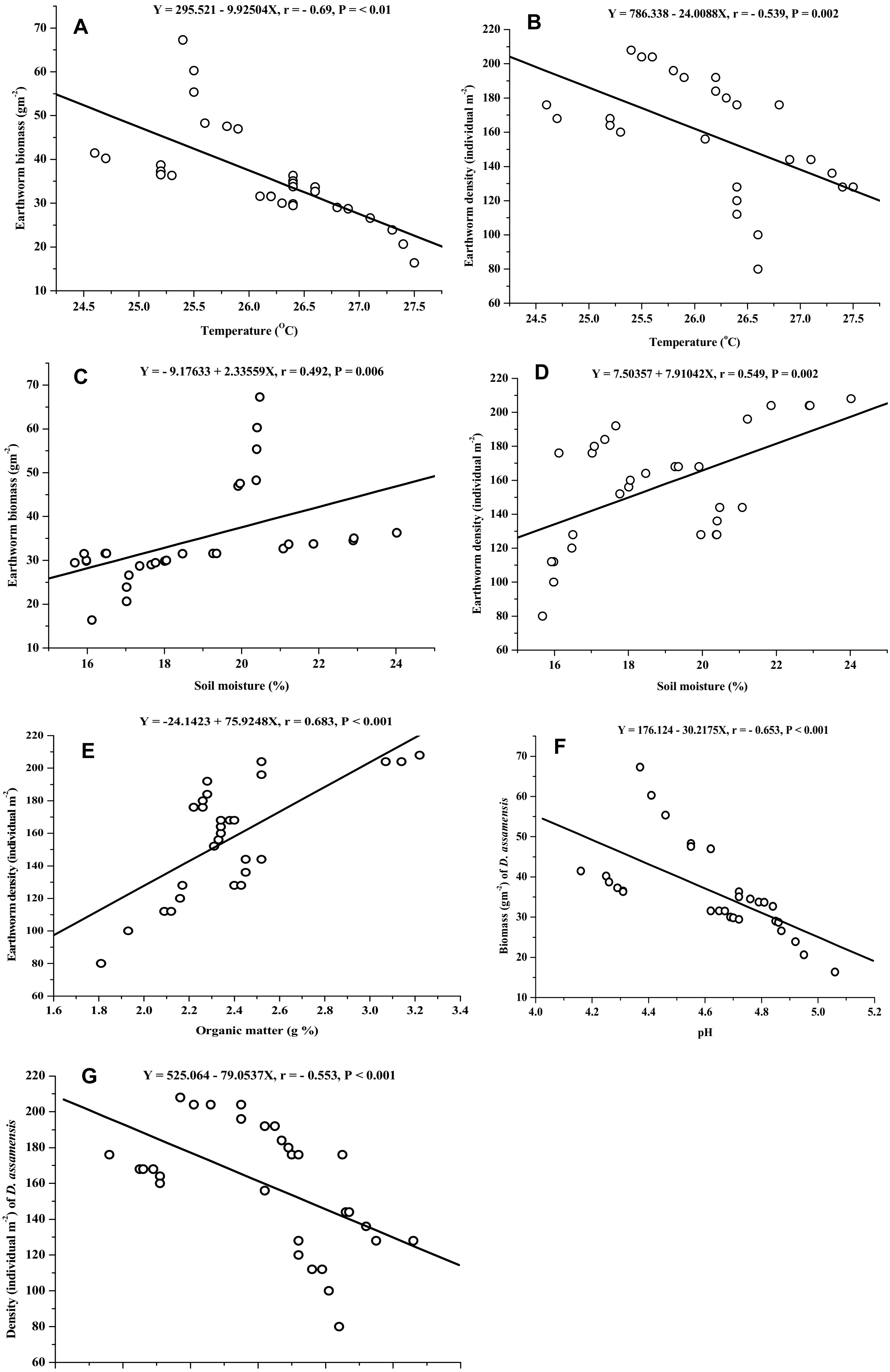

Fig. 6 Relationship between (**A**) Earthworm biomass and soil temperature (**B**) Earthworm density and soil temperature (**C**) Earthworm biomass and soil moisture (**D**) Earthworm density and soil moisture (**E**) Earthworm density and soil organic matter (**F**) Biomass of *Drawida assamensis* and pH (**G**) Density *Drawida assamensis* and pH.

temperate conditions (Whalen and Costa 2003; Whalen 2004; Decaens *et al.* 2008; Valckx *et al.* 2009). Highest value of Morisita's index (I_d) in 15-20 year age group of plantation may be due to greater heterogeneity in soil conditions and food distribution (Whalen 2004) than in other plantation groups. A gradual decrease in the soil environmental heterogeneity (Rossi *et al.* 2006) coupled with decline in the intensity of disturbance (Jimenez *et al.* 2001) with increasing plantation age, may attribute to the decrease in Morisita's index (I_d) i.e. less clumped earthworm community with increase in the pineapple plantation age.

Gradual decrease in the soil temperature with increase in plantation age not only improves soil moisture status but also leads to reduced oxidation of soil organic matter and favours its build up. Thus both moisture and temperature correlate strongly with earthworm density and biomass. Tiwari *et al.* (1992) and Lalthanzara *et al.* (2011) also found a significant correlation between earthworm populations and edaphic factors such as temperature and moisture. According to Edwards and Bohlen (1996) moisture and temperature of soil can act synergistically to influence earthworm population. Significantly ($P < 0.01$) low density and biomass values of earthworms in the 1-5 year old plantations compared to mature plantations is probably due to high temperature and low moisture content of the soil due to direct solar radiation in the plantation floor in absence of canopy cover. Difference in canopy cover, quality and quantity of leaf litter, biotic resistance, variations in the edaphic factors etc. may have triggered changes in the abundance and community structure of earthworms among four plantation age groups. Significantly negative ($P < 0.01$) correlation between pH and population density and biomass of *D. assamensis* indicates its acid tolerant characteristics. According to Spiers *et al.* (1986) acid tolerant earthworm species have a major role in the decomposer subsystem.

According to Sinha *et al.* (2003) and Dey *et al.* (2012), functional guild diversity of earthworm is lower in agro-ecosystems with homogeneous ecological niches, compared to forest ecosystems with varied ecological niches. A pineapple agro-ecosystem is largely dominated by endogeic earthworm species. Epianecic species (*M. houlleti*) forms a minor component of earthworm communities in pineapple plantation. Fragoso *et al.* (1999) also advocated that earthworm communities of tropical agro-ecosystem are composed mostly of endogeic species of earthworms.

In conclusion, *D. assamensis* was the dominant earthworm species of pineapple plantations in Tripura. The earthworm densities and biomasses increased significantly ($P < 0.01$) with increase in the age of pineapple plantation. A significant decrease ($P < 0.05$) in Shannon diversity index and species evenness and significant increase ($P < 0.05$) in dominance index with increase in the age of plantation were remarkable.

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