



# Impact of Rubber Leaf Vermicompost on Tea (*Camellia sinensis*) Yield and Earthworm Population in West Tripura (India)

Priyasankar Chaudhuri, Singh Kwak Santua Jamatia

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## ABSTRACT

**Background:** Vermicompost is a manure produced from organic waste through the activity of epigeic earthworms and microbes. Excessive use of chemical fertilizers for long term to increase the crop productivity have led to deterioration of soil health. Therefore, to assess the effect of vermicompost, as an alternative option to chemical fertilizer, on tea yield and earthworm population, field application of vermicompost on tea plantation was carried out for a period of two years (2015-2016) in Harishnagar Tea Estate, West Tripura, India.

**Methods:** The experimental plot (25 sq. m) was set up using a random block design with 4 different rates of vermicompost viz. T<sub>0</sub> (Control), T<sub>1</sub> (5 t ha<sup>-1</sup> year<sup>-1</sup>), T<sub>2</sub> (10 t ha<sup>-1</sup> year<sup>-1</sup>) and T<sub>3</sub> (15 t ha<sup>-1</sup> year<sup>-1</sup>) each having five replications. Composite soil samples were collected at the beginning and at the end of the experiment. Earthworms were also collected during the experimental period.

**Conclusion:** Application of vermicompost significantly influenced the tea plantation soils, increased the tea yield along with earthworm population and was dependent on the vermicompost doses applied.

**Key words:** Carotenoid, Earthworm, Rubber leaf vermicompost, Tea yield.

## INTRODUCTION

Tea plant (*Camellia sinensis*) is an intensively managed and economically important monoculture cash crop growing under sub-tropical and tropical regions providing a microclimatic environment to both the below and above ground fauna (Saha *et al.*, 2012). The total tea production in the world has exceeded over 4 billion kg year<sup>-1</sup>. India alone contributes to about 1 billion kg year<sup>-1</sup> of tea and recognized as one of the leaders in the world tea production (Shah, 2013). India is the largest producer of black tea sharing about 23 per cent of total world tea production and about 80 per cent of the tea is consumed within the nation itself (Basu *et al.*, 2010).

Excessive use of inorganic fertilizers for crop productivity without organic supplements not only deteriorates the physico-chemical properties of soils but also pollutes the surrounding environment (Haripal and Senapati, 2014), soil sustainability and ecosystem productivity (Chaudhuri, 2019). The increasing concern in environmental issues such as soil degradation and waste recycling for more eco-friendly plant and food production systems, has led in recent years to a significant increase in the use of organic amendments in agriculture (Kale, 2014). Use of chemical fertilizers in tea gardens is extensively practiced to increase and improve the tea productivity and this long-term exploitation of tea plantation soils leads to deterioration of soil fertility (Senapati *et al.*, 1994). In the present scenario, organic farming is gradually replacing conventional farming due to increasing demand for organic food and growing environmental concerns (Benbi *et al.*, 2018). Therefore, it is now crucial to find out alternative ways of fertilizer management in crop cultivation and vermicompost offers one of the best alternatives to inorganic fertilizers (Chaudhuri, 2019).

Earthworm Research Laboratory, Department of Zoology, Tripura University, Suryamaninagar, Agartala-799 022, West Tripura, India.

**Corresponding Author:** Priyasankar Chaudhuri, Earthworm Research Laboratory, Department of Zoology, Tripura University, Suryamaninagar, Agartala-799 022, West Tripura, India.  
Email: priya\_1956@rediffmail.com

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At present, vermicompost is gaining interest as a greener replacement for chemical fertilizer and crop production. Vermicompost is a product of mesophilic biodegradation of organic matter through the activities of earthworms and micro-organisms (Lazcano and Dominguez, 2010). Vermicompost contains plant available nutrients, growth regulators (Edwards *et al.*, 2014), humic acid and phenolic compounds (Bhonwong *et al.*, 2009). Recently, Chaudhuri (2019) proposed that vermicomposting technology could be a promising tool for second green revolution in India. Field application of vermicompost could improve the physical structure of the soil such as soil aggregation, porosity, aeration, drainage and also nutrient uptake by plants (Bhattacharjee *et al.* 2001; Chaudhuri, 2019). The impact of vermicompost on growth and yield of different crops have been well documented in India and other parts of the world (Chaudhuri *et al.* 2016, Maltas *et al.* 2017, Khan *et al.* 2017, Prajapati *et al.* 2018, Siva and Serfoji, 2018). Although several authors (Dutta 2011, Qiu *et al.* 2014,

Huang *et al.* 2016) studied effects of application of nitrogen fertilizers, humic fertilizers and cattle manures on tea productions, till date there is no literature on the impact of vermicompost on tea yield and earthworm population inhabiting tea plantations. Therefore, our present study deals with the effects of vermicompost (organic manure) on the tea leaf productions, growth of tea plant and earthworm population present in the tea plantation of Tripura, a north-eastern state of India.

## MATERIALS AND METHODS

### Experimental site and design

The study was conducted from January 2015 to November 2016 in Harishnagar Tea Estate, Bishalgarh, Tripura (N23°41.943', E91°15.7113', elevation 26 m). The soil physico-chemical properties prior to experiment were: pH 4.1, organic carbon 1.28 per cent, total nitrogen 0.13 per cent, C/N (Carbon:Nitrogen) ratio 9.43, available phosphorus (available P) 9.41 kg ha<sup>-1</sup>, available potassium (available K) 32.14 kg ha<sup>-1</sup>, bulk density 1.64 g cm<sup>-3</sup> and water holding capacity 18.76 per cent. Because of higher growth rate in the young stage, two years old tea plantations on 'tilla' or uplands were selected for vermicompost application. Vermicompost (processed by *Eisenia fetida* from the mixture of rubber leaf litter and cow dung wastes in 1:1 w/w) was supplied by Adharini Vermifertilizer and Research Centre, Bhati Fatikchhera, West Tripura. The source of rubber leaf litter was the rubber plantation located inside the Adharini Vermifertilizer and Research Centre.

In Tripura, more than 60,000 ha areas are under the rubber cultivation. As rubber plants are deciduous, the plantation floor is covered with huge amount of rubber leaf litter throughout the year. Therefore, these rubber leaf litters were utilized for vermicomposting. That rubber leaf litter acts as vermiculture substrate for *Eisenia fetida* and *Eudrilus eugeniae* was earlier reported by Chaudhuri *et al.* (2003). The cow dung was supplied to the Adharini Vermifertilizer and Research Centre from the neighbouring cattle farm. Vermicompost that was supplied to the field had organic carbon 9.36 percent, nitrogen 1.03 per cent, available phosphorus 0.267 g per cent, available potassium 0.348 g per cent, pH 6.20 and C/N ratio 9.08 (Chaudhuri *et al.* 2016). The experiment was set up using a complete random block design (RBD) with four different amounts of vermicompost each having five replications. Each experimental plot was 25 sq. m (5 m × 5 m) and had 4 rows with 6 plants in each row (a total 24 plants in each plot). The dose of vermicompost applied to the experimental plots was T<sub>0</sub> (Control), T<sub>1</sub> (5 t ha<sup>-1</sup> year<sup>-1</sup>), T<sub>2</sub> (10 t ha<sup>-1</sup> year<sup>-1</sup>) and T<sub>3</sub> (15 t ha<sup>-1</sup> year<sup>-1</sup>). The prescribed dose per treatment was divided equally into 3 parts and each part was applied at an interval of 4 months in a year. Thus, each experimental plot received a total of six applications of vermicompost from January 2015 to September 2016. Each individual plant of T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub> treatments per replicated plots of 25 sq. m received a total of 0.42, 0.82 and 1.24 kg vermicompost yr<sup>-1</sup> respectively.

Thus, a total of 120 tea plants (for a total of five replications) per treatment received an equal proportion of vermicompost. The control plot received neither vermicompost nor any chemical fertilizers during the entire experimental period. Prior to application of vermicompost, the experimental plots were not subjected to addition of any chemical fertilizer.

### Plant growth attributes

Evaluation of different tea plant parameters such as the mean of basal plant girth, tea leaf pluckings per plant, leaf length, leaf width and total leaf productions in each experimental plot was assessed for two years (2015-2016). Young two to three tea leaves emerging from the canopy of the plant were plucked weekly from each plant and from these pluckings, leaf length and breadth, total fresh tea leaf productions (yield) were determined for each treatment plots (120 plants per treatment). Pluckings were done for a period of 7 months (May to November) for two years (2015-2016). Tea leaf productions were expressed as tonnes hectare<sup>-1</sup> year<sup>-1</sup> (t ha<sup>-1</sup> yr<sup>-1</sup>).

### Analysis of tea leaf chemistry

Freshly plucked tea leaves were sent to Indian Institute of Chemical Biology (CSIR, Kolkata, West Bengal India) for determination of total phenolic and flavonoid contents in tea leaves of each treatment plot following the termination of the experiment. The total phenolic content was expressed in mg of Gallic Acid Equivalent per g of dry weight (mg GAE g<sup>-1</sup>). The content of flavonoids was expressed in mg of Quercetin Equivalent per g of dry weight (mg QE g<sup>-1</sup>). For determination of total chlorophyll and carotenoid content of tea leaves, standard procedure was followed (Rajalakshmi and Banu, 2013).

### Earthworm extraction and collection

Earthworms were collected by TSBF monolith (25 cm × 25 cm × 40 cm) hand-sorting method (Anderson and Ingram, 1993) during the experimental period (2015-2016) to determine the effect of vermicompost on the earthworm community structure in the tea plantation. Sampling was done during the peak activity period of earthworms (August to October). Collected data on earthworms were expressed in terms of density (ind. m<sup>-2</sup>) and biomass (g m<sup>-2</sup>).

### Soil sample collection and analysis

The soil samples were collected at the beginning (January 2015) and at the end (November 2016) of the experiment for physico-chemical analysis. Composite soil samples from control and each experimental plot were collected from 5-10 cm soil depth. The pH was measured in 1:2.5 (w/v) aqueous solution using EUTECH digital pH meter. Bulk density and water holding capacity were estimated using a core method (Dash and Dash, 2009). The soil organic carbon was determined using potassium dichromate oxidation procedure (Walkley and Black, 1934) and total soil nitrogen was measured by the Kjeldahl method (Jackson, 1975). Available phosphorus and potassium were determined following the standard procedures (Kuo 1996, Jones 2001).

## Statistical analysis

Variations in different tea plant parameters, soil physico-chemical properties and earthworm population characteristics were tested separately for 2015 and 2016 by ANOVA at 5 per cent level of significance and significant differences among two years (2015 and 2016) were tested by using two tailed-paired sample t-test. The principal component analysis was performed to analyse the relation amongst plant growth parameters, earthworm density and biomass with the soil physico-chemical properties.

## RESULTS AND DISCUSSION

### Soil physico-chemical properties

Application of vermicompost influenced significantly the pH, organic carbon, total nitrogen contents, C/N ratio, available phosphorus and potassium, water holding capacity and bulk density of the tea plantation soil, but the impact were subjected to the dose of the vermicompost dosages applied (Table 1). Soil pH values increased significantly ( $p < 0.05$ ) with an increase in doses of vermicompost and was observed highest in case of  $T_3$  (Table 1). A steady increase in the soil pH following application of increasing doses of vermicompost was due to the fact that the initial soil pH of tea plantation was 4.01 which afterwards gradually increased when subjected to the vermicompost with higher pH value (6.2). A steady increase in the soil pH with increasing doses of vermicompost (up to  $15 \text{ t ha}^{-1} \text{ yr}^{-1}$  in  $T_3$ ) was also reported by Lazcano and Dominguez (2010) and Chaudhuri *et al.* (2016). Recently, Huang *et al.* (2016) had reported an increase in the soil pH after the application of humic acid into the tea plantations of China. In fact, vermicompost acts as a buffer that increases pH in acidic soils and lowers pH in alkaline soil.

A total of 54, 66 and 82 per cent increase in soil organic carbon were observed in case of  $T_1$ ,  $T_2$  and  $T_3$  plots, respectively in contrast to the control ( $T_0$ ). The highest value of organic carbon (2.33 %) was attained in case of  $T_3$  plot which was significantly higher ( $p < 0.05$ ) than that of  $T_0$ ,  $T_1$  and  $T_2$ . The organic carbon in vermicompost releases the nutrients slowly and steadily into the soil and enables the

plants to absorb the available nutrients (Lalitha *et al.*, 2000). Thus, application of vermicompost as soil amendment build-up soil organic carbon (Tharmaraj *et al.*, 2011).

Among the experimental plots, the  $T_3$  plot exhibited significantly ( $p < 0.05$ ) highest water holding capacity (21.7%) and lowest bulk density ( $1.34 \text{ g cm}^{-3}$ ) (Table 1). The addition of vermicompost enhances soil physical properties of tea plantations by diminishing soil bulk density and increasing the soil water holding capacity (Moradi *et al.*, 2014).

Increasing amounts of vermicompost had an impact on the total nitrogen content of the soils positively. In contrast to control ( $T_0$ ), the total soil nitrogen content was increased by 38 per cent in  $T_3$  plot ( $15 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) that received the highest quantity of vermicompost. Many workers also reported significant increase in the amount of total nitrogen in the field after application of vermicompost (Ansari and Sukhraj 2010, Chaudhuri *et al.* 2016). Recently, Tabu *et al.* (2015) reported a higher nitrogen levels in tea leaves with its better quality and yield following application of enriched cattle manure.

The amount of available soil phosphorus and potassium in the soil also increased gradually with application of higher doses of vermicompost (Table 1). The highest amount of 501 per cent and lowest of 156 percent in the amount of available phosphorus were observed in the soils of  $T_3$  and  $T_1$  plots, respectively when compared to control plot ( $T_0$ ). Likewise, with vermicompost application, the lowest (133%) and the highest (319%) of available potassium were recorded in  $T_1$  and  $T_3$  plots, respectively (Table 1). Among all the treatment plots, the amount of available soil phosphorus and potassium in the  $T_3$  plot was significantly ( $p < 0.05$ ) highest. Significant increase in the amount of available phosphorus and potassium in the soils of tea plantation was due to the application of increasing doses of vermicompost (Chanda *et al.* 2011, Chaudhuri *et al.* 2016).

Enhanced nutrient uptake by plants with increase in production of upland paddy (var. TRC-87-251) in Tripura following application of vermicompost had earlier been reported by Bhattacharjee *et al.* (2001). They reported that the nutrient uptake in general, was greatly increased with increasing doses of vermicompost up to a level of  $15 \text{ t ha}^{-1} \text{ yr}^{-1}$

**Table 1:** Soil physico-chemical properties as influenced by different doses of vermicompost ( $n=3$ ) (Mean  $\pm$  S.E.).

Soil parameters	Treatments				F	P
	$T_0$	$T_1$	$T_2$	$T_3$		
Soil pH (1:2.5)	$4.01 \pm 0.005a$	$4.79 \pm 0.01b$	$5.16 \pm 0.01c$	$5.49 \pm 0.01d$	2004	<0.05
Organic carbon (%)	$1.28 \pm 0.01a$	$1.97 \pm 0.06b$	$2.13 \pm 0.04c$	$2.33 \pm 0.05d$	70.96	<0.05
Total nitrogen (%)	$0.13 \pm 0.001a$	$0.15 \pm 0.001b$	$0.16 \pm 0.001c$	$0.18 \pm 0.001d$	137.9	<0.05
C/N ratio	$9.43 \pm 0.12a$	$12.81 \pm 0.59b$	$12.92 \pm 0.16bc$	$12.55 \pm 0.36d$	20.95	<0.05
Available P ( $\text{kg ha}^{-1}$ )	$9.41 \pm 0.17a$	$24.17 \pm 1.55b$	$43.49 \pm 2.83c$	$56.56 \pm 1.38d$	139.3	<0.05
Available K ( $\text{kg ha}^{-1}$ )	$32.14 \pm 0.14a$	$75.04 \pm 0.64b$	$92.40 \pm 0.56c$	$134.96 \pm 2.48d$	1047	<0.05
Bulk density ( $\text{g cm}^{-3}$ )	$1.64 \pm 0.02a$	$1.54 \pm 0.03ab$	$1.47 \pm 0.03b$	$1.34 \pm 0.04c$	16.21	<0.05
Water holding capacity (%)	$18.76 \pm 0.15a$	$19.92 \pm 0.27ab$	$20.88 \pm 0.17b$	$21.70 \pm 0.11c$	46.22	<0.05

Different letters (a,b,c,d) denotes significant difference.

$T_0$ : Control;  $T_1$ :  $5 \text{ t ha}^{-1} \text{ yr}^{-1}$ ;  $T_2$ :  $10 \text{ t ha}^{-1} \text{ yr}^{-1}$ ;  $T_3$ :  $15 \text{ t ha}^{-1} \text{ yr}^{-1}$ .

and there was a great increase in nutrient uptake when NPK was applied along with vermicompost compared with lone usage of either vermicompost or NPK. Earlier, Kale *et al.* (1992) and Shi-wei and Fu-zhen (1992) also reported that chemical fertilizer application along with vermicompost reduced the loss of nutrients through leaching from the soil by changing the soil physico-chemical properties. Continuous reduction in soil C/N ratio with increasing doses of vermicompost applied to the tea plantation indicates higher rate of mineralization resulting in the accessibility of micronutrients for plant growth (Ansari and Sukhraj, 2010).

#### Tea plant parameters and tea yield

Increasing doses of vermicompost had significant impact on the overall growth parameters of the tea plants *viz.* number of pluckings per plant, mean leaf length and width and total leaf yield. A significantly highest tea leaf plucking per plant were observed in  $T_3$  in both the years (9.26 in 2015 and 10.17 in 2016) (Table 3). Increasing doses of vermicompost significantly ( $p<0.05$ ) increased the tea leaves plucking per plant. The mean tea leaf length and leaf width of different treatments differed significantly ( $p<0.05$ ) compared to control during both the years. A significant ( $p<0.05$ ) increase in the leaf length (8.56 cm in 2015 and 8.81 cm in 2016) and leaf width (3.32 cm in 2015 and 3.55 cm in 2016) was observed in  $T_3$  in both the years among all the treatment plots (Table 3). The total tea leaf yield *i.e.* total leaf productions ( $t\ ha^{-1}\ yr^{-1}$ ) were directly related to the number of tea leaf pluckings per plant. Although, there was increase in the yield of tea leaves in all the treatment plots compared to control,  $T_3$  plot attained significant ( $p<0.01$ ) and the highest total leaf yield in 2015 and 2016 (21.61 and 23.09  $t\ ha^{-1}\ yr^{-1}$ , respectively) (Table 3). Furthermore, tea yield in  $T_3$  in the second year was significantly ( $p<0.05$ ) higher than the first year. While all the treatment plots had much better yield than the control plot ( $T_0$ ) in both the years (2015-2016), the total tea leaf yield was significantly ( $p<0.05$ ) higher in the subsequent year (2016) than in the first year (2015) because of residual effect of the vermicompost application. Organic manure (vermicompost) releases plant nutrients slowly into the soil thus making it available to the plants for the longer period of time (Eghball *et al.*, 2004). Several authors (Reeve *et al.* 2011, Mukhtar *et al.* 2018) have also reported an increase in the crop productivity due to the residual effects of manure or compost application which can last for several years. There was significant

( $p<0.05$ ) increase in the plant girth in the second year when each of the respective treatment plot was compared between the two years (Table 3). Results of two years data indicated that the significantly ( $p<0.05$ ) highest plant girth was observed in  $T_3$ , however,  $T_0$ ,  $T_1$  and  $T_2$  was at par in both the years (2015-2016).

#### Chemical properties of tea leaf

In the present study, the total content of chlorophyll and carotenoid in the tea leaves of treated plots showed a gradual increasing trend with an increase in the amount of vermicompost applied to the treatment plots. The treatment of  $T_3$  recorded the highest total chlorophyll and carotenoid content (Table 2). The highest ( $8.25\ mg\ g^{-1}$ ) and lowest ( $4.73\ mg\ g^{-1}$ ) chlorophyll content was observed in  $T_3$  and  $T_0$ , respectively among all the experimental plots. Similarly, the lowest and highest carotenoid ( $mg\ g^{-1}$ ) was observed in  $T_0$  ( $0.035\ mg\ g^{-1}$ ) and  $T_3$  ( $0.052\ mg\ g^{-1}$ ) treatments, respectively (Table 2). Taie *et al.* (2010) reported that significantly higher chlorophyll content in sweet basil in organic applied plots was observed than in non-fertilized control plants. Increased total carotenoid level in tea plants in response to vermicompost treatments was associated with improved plant growth (Pant *et al.*, 2011). Phenolic and flavonoid contents are associated with the flavour of tea leaves. The total phenolic and flavonoid contents of the tea leaves were significantly higher ( $p<0.05$ ) in the  $T_3$  plots compared to other treatments (Table 2). Organically grown crops mostly contain higher levels of phenolic metabolites and flavonoid content than conventionally grown crops (Khalid *et al.* 2006, Bagchi *et al.* 2015).

#### Earthworm species composition, density and biomass

A total of only three earthworm species *viz.* *Pontoscolex corethrurus*, *Drawida assamensis* and *Metaphire houlleti* were observed in control and experimental plots while sampling during the two years. These three species along with other earthworm species were reported by Jamatia and Chaudhuri (2017a) in the soils of tea plantation. Based on relative density, *P. corethrurus* was the most common earthworm species (60%) followed by *M. houlleti* (24%) and *D. assamensis* (15%). A significant ( $p<0.01$ ) increase in the density and biomass of earthworms (up to  $T_3$  treatment) in second year (2016) were noteworthy along with the increasing doses of vermicompost (Table 3). Among the different treatment plots, the highest earthworm density and

**Table 2:** Chemical properties of tea leaf as influenced by different doses of vermicompost ( $n=3$ ) (Mean  $\pm$  S.E.).

Parameters	Treatments				F	P
	$T_0$	$T_1$	$T_2$	$T_3$		
Total chlorophyll ( $mg\ g^{-1}$ )	4.73 $\pm$ 1.05a	5.82 $\pm$ 0.18b	6.45 $\pm$ 0.13b	8.25 $\pm$ 0.36c	44.81	<0.05
Carotenoid ( $mg\ g^{-1}$ )	0.03 $\pm$ 0.006a	0.041 $\pm$ 0.003b	0.043 $\pm$ 0.001b	0.052 $\pm$ 0.002c	17.76	<0.05
Total phenolic content ( $mg\ GAE\ g^{-1}$ )	0.495 $\pm$ 0.02a	0.497 $\pm$ 0.05a	0.528 $\pm$ 0.065b	0.552 $\pm$ 0.07bc	18.27	<0.05
Total flavonoid content ( $mg\ QE\ g^{-1}$ )	1.33 $\pm$ 0.03a	1.41 $\pm$ 0.03b	1.42 $\pm$ 0.04b	1.56 $\pm$ 0.06c	27.53	<0.05

Different letters (a,b,c) denotes significant difference.

$T_0$ : Control;  $T_1$ : 5  $t\ ha^{-1}\ yr^{-1}$ ;  $T_2$ : 10  $t\ ha^{-1}\ yr^{-1}$ ;  $T_3$ : 15  $t\ ha^{-1}\ yr^{-1}$ .

**Table 3:** Different tea plant parameters and earthworm population as influenced by different doses of vermicompost in tea plantation plots (Mean  $\pm$  S.E.).

Parameters	Year	Treatments				F	P
		T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>		
Plant girth (cm)	2015	6.02 $\pm$ 0.08a*	6.04 $\pm$ 0.07a*	6.12 $\pm$ 0.06a*	6.35 $\pm$ 0.04b*	3.48	< 0.05
	2016	6.63 $\pm$ 0.06a*	6.58 $\pm$ 0.05a*	6.65 $\pm$ 0.07a*	7.51 $\pm$ 0.11b*	34.12	< 0.05
	Avg.	6.33 $\pm$ 0.06a	6.31 $\pm$ 0.05a	6.39 $\pm$ 0.05a	6.91 $\pm$ 0.08b	17.79	<0.01
Leaf length (cm)	2015	6.25 $\pm$ 0.11a*	6.98 $\pm$ 0.09b*	7.69 $\pm$ 0.06c*	8.56 $\pm$ 0.06d*	131.3	< 0.05
	2016	6.85 $\pm$ 0.08a*	7.27 $\pm$ 0.09b*	7.92 $\pm$ 0.06c*	8.81 $\pm$ 0.07d*	112.4	< 0.05
	Avg.	6.55 $\pm$ 0.07a	7.13 $\pm$ 0.06b	7.80 $\pm$ 0.04c	8.68 $\pm$ 0.04d	235.1	<0.01
Leaf width (cm)	2015	2.60 $\pm$ 0.04a	2.65 $\pm$ 0.04b*	3.14 $\pm$ 0.05c*	3.32 $\pm$ 0.04d*	99.55	< 0.05
	2016	2.64 $\pm$ 0.02a	2.81 $\pm$ 0.05b*	3.29 $\pm$ 0.03c*	3.55 $\pm$ 0.03d*	313.1	< 0.05
	Avg.	2.62 $\pm$ 0.02a	2.72 $\pm$ 0.02b	3.21 $\pm$ 0.02c	3.43 $\pm$ 0.02d	221.8	<0.01
No. of leaf pluckings per plant	2015	3.94 $\pm$ 0.12a*	5.43 $\pm$ 0.14b*	7.19 $\pm$ 0.14c*	9.26 $\pm$ 0.12d*	281.3	< 0.05
	2016	4.38 $\pm$ 0.14a*	5.85 $\pm$ 0.15b*	7.65 $\pm$ 0.16c*	10.17 $\pm$ 0.17d*	240.2	< 0.01
	Avg.	4.16 $\pm$ 0.09a	5.64 $\pm$ 0.11b	7.42 $\pm$ 0.11c	9.72 $\pm$ 0.11d	505.6	<0.01
Total leaf productions (t ha <sup>-1</sup> yr <sup>-1</sup> )	2015	12.12 $\pm$ 0.11a	13.67 $\pm$ 0.12a	15.33 $\pm$ 0.13b*	21.61 $\pm$ 0.19c*	15.17	< 0.01
	2016	13.04 $\pm$ 0.11a	14.65 $\pm$ 0.13b	16.46 $\pm$ 0.14c*	23.09 $\pm$ 0.20d*	19.73	< 0.01
	Avg.	12.58 $\pm$ 0.46a	14.16 $\pm$ 0.49ab	15.91 $\pm$ 0.56b	22.35 $\pm$ 0.73c	55.84	<0.01
Earthworm density (ind. m <sup>-2</sup> )	2015	33.66 $\pm$ 3.24a*	44.33 $\pm$ 3.54b*	72.66 $\pm$ 5.53c*	101.33 $\pm$ 3.51d*	51.57	< 0.01
	2016	49.21 $\pm$ 3.94a*	55.26 $\pm$ 3.83a*	82.33 $\pm$ 6.37b*	113.67 $\pm$ 5.28c*	35.26	< 0.01
	Avg.	42.66 $\pm$ 2.67a	49.5 $\pm$ 2.64a	77.5 $\pm$ 4.22b	107.5 $\pm$ 3.22c	82.58	<0.01
Earthworm biomass (g m <sup>-2</sup> )	2015	9.82 $\pm$ 1.22a*	11.91 $\pm$ 1.23b*	20.21 $\pm$ 1.95c*	26.98 $\pm$ 1.48d*	27.4	< 0.05
	2016	11.34 $\pm$ 1.28a*	13.61 $\pm$ 1.16a*	24.72 $\pm$ 1.58b*	28.54 $\pm$ 1.47c*	15.51	< 0.05
	Avg.	10.60 $\pm$ 0.88a	12.76 $\pm$ 0.84a	22.47 $\pm$ 2.04b	27.76 $\pm$ 1.04c	38.65	<0.01

Different letters (a,b,c,d) denotes significant difference in a single year; Earthworm data, n=60.

\*indicates significant (p<0.05) difference within a parameter of a single treatment between two years (2015-2016).

T<sub>0</sub>: Control; T<sub>1</sub>: 5 t ha<sup>-1</sup> yr<sup>-1</sup>; T<sub>2</sub>: 10 t ha<sup>-1</sup> yr<sup>-1</sup>; T<sub>3</sub>: 15 t ha<sup>-1</sup> yr<sup>-1</sup>.

Avg. is the mean value of the two years (2015-2016) combined.

biomass were recorded in T<sub>3</sub> treatment plots in both the years (Table 3). Earthworm density fluctuated from 44 ind. m<sup>-2</sup> in T<sub>1</sub> to 101 ind. m<sup>-2</sup> in T<sub>3</sub> during the first year (2015) and 55 ind. m<sup>-2</sup> in T<sub>1</sub> to 113 ind. m<sup>-2</sup> in T<sub>3</sub> during the second year (2016). On the other hand, earthworm biomass varied from 11.91 g m<sup>-2</sup> in T<sub>1</sub> to 26.98 g m<sup>-2</sup> in T<sub>3</sub> during first year (2015) and 13.61 g m<sup>-2</sup> to 28.54 g m<sup>-2</sup> in T<sub>1</sub> and T<sub>3</sub> treatment plot, respectively during the second year (2016) (Table 3). A gradual increment in the population density and biomass of earthworms in the experimental plots with increasing doses of vermicompost and the highest being in T<sub>3</sub> treatment plot are the most important factor associated with improvement of soil physico-chemical status. There was no change in the earthworm species composition following application of vermicompost for successive two years (2015-2016). Chaudhuri *et al.* (2016) also did not find any change in the earthworm species composition in the vermicompost treated pineapple field in West Tripura. Increase in earthworm biomass and density in relation to total soil nitrogen, organic carbon and available soil phosphorus was earlier reported by Chaudhuri *et al.* (2016) in the vermicompost treated plot of pineapple plantation. Najar and Khan (2014) and Chaudhuri *et al.* (2016) have reported the positive impact of increasing soil pH and available soil potassium on earthworm population

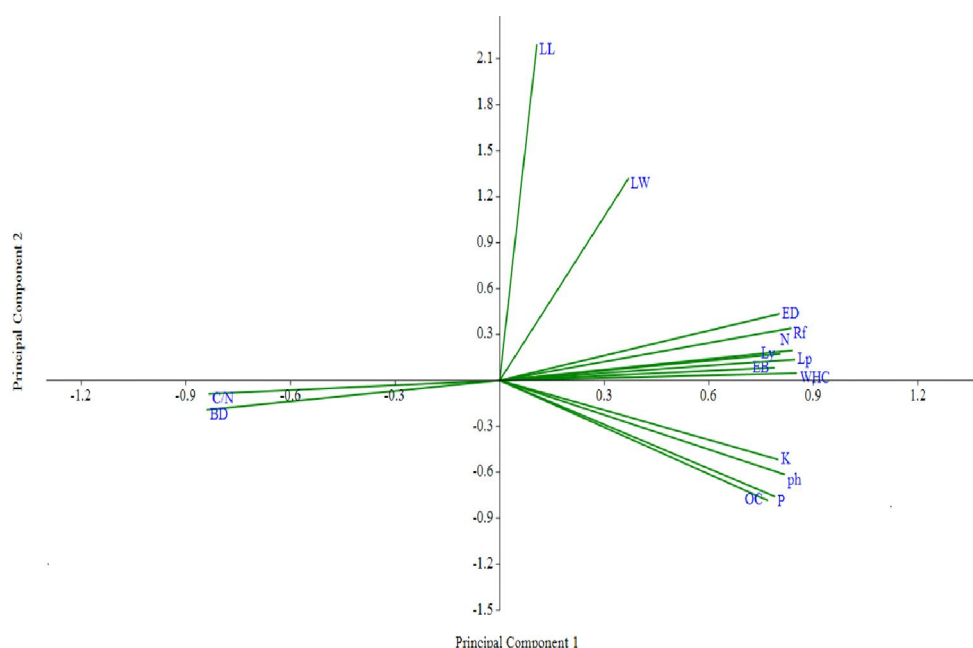
density. Dominance of exotic earthworm, *Pontoscolex corethrurus* in the studied site was possibly due to anthropogenic practices in the tea plantations (Jamatia and Chaudhuri, 2017b).

#### Principal component analysis

The results of the principal component analysis of the soil physical and chemical properties, plant morphological characters and earthworm community are provided in Fig 1. Eigen values greater than 1 was taken as a measure for determination of the principal components required to explain the sources of variance in the data of tea leaf yield (Table 4). Eigen value (12.88) of principal component 1 exhibited that samples were mainly separated along with

**Table 4:** Principal component eigen analysis of the correlation matrix.

Components	Eigen value	Percentage of variation	Cumulative percentage of variation
1	12.88	80.56	80.56
2	1.54	9.65	90.21
3	0.69	4.34	94.55
4	0.38	2.38	96.93
5	0.19	1.22	98.16



**Fig 1:** Principal component analysis performed with the plant growth, soil physico-chemical and earthworm community parameters (n=15). [ED- Earthworm density, EB- Earthworm biomass, LL- Leaf length, LW- Leaf width, Lp- Leaf plucks, Ly- Leaf yield, N- Total nitrogen, WHC- Water holding capacity, BD- Bulk density, K- Available potassium, P- Available phosphorus, OC- Organic carbon, Rf-Rainfall, C/N- Carbon:nitrogen ratio].

the primary axis which clarified about 80 percent of the total variance (Table 4). The principal component 1 had strong positive loadings (>0.75) of soil physico-chemical properties (pH, organic carbon, total nitrogen, available phosphorus, available potassium, water holding capacity), rainfall, leaf plucking and leaf yield; moderate positive loadings (0.50-0.75) of leaf width and leaf length. Soil parameters like bulk density and C/N ratio showed negative loadings (Fig 1). The principal component 2 (Eigen value 1.54) had weak negative loadings with soil parameters like organic carbon and available phosphorus while strong and moderate positive loadings with leaf length and leaf width respectively. Based on principal component analysis, it appears that enhanced tea leaf growth, leaf pluckings and total tea leaf yield are strongly related with soil pH, available phosphorus, available potassium and earthworm density of the soil, which are in agreement with the findings of Ganeshamurthy *et al.* (2011) and Chaudhuri *et al.* (2016). The variations of earthworm biomass are related to soil properties and site conditions (Irannejad and Rahmani, 2009). According to Nath and Chaudhuri (2010), earthworm abundance showed negative correlation with increasing soil pH which is probably due to the dominance of highly acidic soil tolerant exotic species, *P. corethrurus* found in the experimental plots of the tea plantation. Dey and Chaudhuri (2014) had also reported a negative correlation between soil pH and native earthworm, *D. assamensis*. Iordache and Borza (2010) found out a negative correlation of pH and phosphorus with earthworm number and biomass. They reported that the phosphorous content of soil exerted negative influence on earthworm biomass.

Field application of vermicompost indicated its strong association with tea plant development and yield. Recently, Chen *et al.* (2014) and Huang *et al.* (2016) had reported that the tea leaves' yield and quality could be effectively increased and improved by using humic acid fertilizers in the tea garden soils. Several earlier studies have demonstrated that vermicompost played an essential part in enhancing development and yield of various crops including vegetables, flowers and fruits (Karmegam and Daniel 2000, Kale 2014, Chaudhuri *et al.* 2016). Improvement in the tea plant development and yield may be ascribed to biological impacts *viz.*, enhancement in beneficial enzyme activities, increased beneficial microbial population, or the presence of biologically dynamic plant development stimulating factors like plant growth regulators (or hormones) present in vermicomposts (Kale *et al.* 1992, Tomati and Galli 1995, Subler *et al.* 1998) and humic acids (Arancon *et al.*, 2006).

## CONCLUSION

From the current study, it can be concluded that there is gradual and significant increase in pH, organic carbon, nitrogen, available phosphorus, available potassium, water holding capacity, decrease in soil bulk density along with increase in tea yield and earthworm population following application of increasing dose of vermicompost in tea plantation soils. Usage of vermicompost in the tropical soils of tea agro-biological system promotes plant development and enhances yield of tea plants through increase in the density and biomass of earthworms and improvement in the

physico-chemical properties of soil. Application of vermicompost in the tea plantations of Tripura may provide a better alternative for improving the soil fertility along with tea productivity than excessive usage of chemical fertilizers.

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