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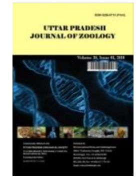

EARTHWORM CASTING ACTIVITY AND THEIR NUTRIENT CONTRIBUTION TO THE SOILS OF PASTURE, NATURAL FOREST AND RUBBER PLANTATION IN TRIPURA INDIA

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AUTHORS' CONTRIBUTIONS
This work was carried out in collaboration between both authors. Author BD carried out the research work and performed the statistical analysis. Author PC supervised the research work and helped to prepare the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Present study revealed casts of a total of 9 earthworm species (*Eutyphoeus assamensis*, *E. comillahnus*, *E. scutarius*, *E. gigas*, *Lampito mauritii*, *Kanchuria* sp., *Metaphire houlleti*, *Pontoscolex corethrurus* and *Glyphidrilus* sp.) from three land-use systems (pasture, natural forest and rubber plantation) of West Tripura and Sepahijala districts of Tripura, India. Different species of earthworms voided casts in different forms i.e. granular, globular or tower like. Strong positive correlation was found between earthworm body weight and diameter of casts ($r = 0.68$, $P = 0.01$). Among the three studied ecosystems, natural forest had the highest annual casts production of 23.44 tonnes ha^{-1} $year^{-1}$. On the other hand pasture and rubber plantation exhibited an annual cast production of 11.16 tonnes ha^{-1} $year^{-1}$ and 9.92 tonnes ha^{-1} $year^{-1}$ respectively. Out of 9 earthworm species, *E. assamensis*, *P. corethrurus* and *L. mauritii* contributed the highest annual cast production of 8.44 tonnes $ha^{-1}year^{-1}$, 6.65 tonnes $ha^{-1}year^{-1}$ and 5.00 tonnes $ha^{-1}year^{-1}$ under natural forest, rubber plantation and pasture respectively. Significant positive correlation was observed between cast production vs. rainfall (pasture: $r = 0.59$, $P < .05$; natural forest: $r = 0.48$, $P < .05$; rubber plantation: $r = 0.69$, $P < .05$), cast production vs. temperature (pasture: $r = 0.51$, $P < .05$; natural forest: $r = 0.54$, $P < .05$; rubber plantation: $r = 0.52$, $P < .05$) and cast production vs. moisture (pasture: $r = 0.59$, $P < .05$; natural forest: $r = 0.62$, $P < .05$; rubber plantation: $r = 0.66$, $P < .05$). The peak of cast production in earthworm species coincided during the monsoon period in our present study. Analysis of physical properties of earthworm casts and its surrounding soils revealed that casts had a significantly ($P < .05$) higher pH and moisture values compared to non-ingested soils. The chemical

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analysis of earthworm casts revealed that casts were significantly (P < .05) rich in organic C, as well as, in total N, av. P and av. K compared to their surrounding soils.

Keywords: Earthworm casts; annual cast production; pasture; natural forest; rubber plantation.

1. INTRODUCTION

In present days highly diverse native forests are declining at a rapid rate due to human activities that lead to the conversion of natural forests to pasture and perennial crop lands such as rubber plantations. In consequence, there are effects on reduction in the structural and functional biodiversity in the ecosystems and soil carbon stocks [1]. In this situation, the role of earthworms becomes more important as major soil ecosystem engineers, as they improve soil fertility through their feeding, burrowing and casting activity [2]. Yonekura et al. [3] emphasized the importance of earthworms in the recovery of soil carbon stock after the establishment of grassland by deforestation in the Asian humid tropics. Moreover, earthworm has a great role in organic matter turnover through decomposition of large quantities of leaf litters was reported earlier [4]. Casts produced by earthworms richer in plant-available nutrients and organic matter than the non-ingested soil, largely affects plant growth [5,6]. Earthworm ingests mineral soil along with organic matter and passes it through the gut enriched in microorganisms, as well as, mixed with mucus, many changes occur in its physicochemical properties until they are egested as casts within or upon the soil [7, 8]. Fresh earthworm casts showed higher microbial activity but with time casts become drier and microbial activity slows down [9,10]. Dried earthworm casts are stable soil aggregates that protect the organic carbon from rapid mineralization and increase the residence time of soil carbon [11-13]. So, it is reasonable to assume that earthworms and their casts have a great role in land reclamation and soil carbon conservation. Recently the roles of anecic and endogeic earthworms in soil carbon sequestration have been advocated by Don et al. [14] and Wu et al. [15].

Earthworm casts production depends on different soil physicochemical properties as well as habitat suitability and food availability [16]. The number of casts produced serves as an index for assessing earthworm activity [17]. In tropical regions annual cast production ranging from 3.9 - 77.8 tonnes ha^{-1} year^{-1} in India to as much as 173.0 – 222.3 tonnes ha^{-1} year^{-1} in Nigeria have been reported [17,18]. Earthworm casting activities in the grasslands of Orissa, India were recorded by Dash and Patra [19]. Annual cast production by earthworm *Pheretima alexandri* was studied by Reddy [20]. Suthar [21] assessed earthworm cast production and nutrient cycling under the semiarid ecosystems of Rajasthan, India. Still, information on earthworm casts and their nutrient contents under different land-use systems in north east India is scanty [16]. Therefore, the present investigation was conducted to study the earthworm surface cast production and physicochemical properties of casts and surrounding soils under three land-use systems (pastures, natural forests and rubber plantations) in Tripura, India.

2. MATERIALS AND METHODS

2.1 Study Sites and Area

Studies on earthworm casting activities were carried out under pastures, natural forest and rubber plantations (two different sites considered for each habitat) in West Tripura and Sepahijala district in Tripura, India for two years (January 2017 to December 2018). Tripura, a north-eastern state of India with an area of 10,491 km^2 (latitude 22°51' - 24°32' N and 90°10' - 92°21' E) is surrounded by Assam and Mizoram to the east and Bangladesh to the north, south, and west. The studied sites experience a subtropical humid climate with an average annual rainfall of about 2000 mm and a mean temperature of 25°C. The year in this region is divisible into four seasons, namely summer (April - June), monsoon (July - October), winter (November - February) and spring (March). Herbaceous species such as- *Isachne globosa* (Poaceae), *Axonopus compressus* (Poaceae), *Eleusine indica* (Poaceae), *Cynodon dactylon* (Poaceae), *Panicum repens* (Poaceae), *Desmodium triflorum* (Fabaceae), *Mimosa pudica* (Fabaceae), *Leucas aspera* (Lamiaceae) etc. were distributed in the pasture ecosystems. On the other hand, the natural forest had a good canopy cover of trees along with various herbs and shrubs such as *Spilanthes paniculata* (Asteraceae), *Trema orientalis* (Cannabaceae), *Manihot esculenta* (Euphorbiaceae), *Ageratum* sp. (Asteraceae), *Bauhinia* sp (Fabaceae), *Ziziphus* sp. (Rhamnaceae), *Chromolaena odorata* (Asteraceae), *Justicia adhatoda* (Acanthaceae), *Tectona grandis* (Lamiaceae), *Musa paradisiaca* (Musaceae), *Microcos paniculata* (Tiliaceae), *Spondias pinnata* (Anacardiaceae), *Albizia procera* (Mimosaceae). Due to human interference such as regular maintenance of rubber plantations for latex collection, plant diversity is very poor. Only a few herbs and shrubs were observed during the study such as *Mimosa pudica* (Mimosaceae), *Spilanthes* *paniculata* (Asteraceae), *Chromolaena odorata* (Asteraceae), *Blumea* sp. (Asteraceae) for example.

2.2 Collection of Earthworm Casts

For investigating monthly variations in year-round cast production, earthworm casts were collected at a monthly interval. Only fresh earthworm casts present on the soil surface were considered during the study. Samplings were done every second week of a month. During the study period, 10 quadrats (1 m × 1 m size) 10 m apart from each other were taken per month. After the collection of fresh casts, earthworms were collected immediately from the same sampling point following digging (25×25×30 cm) and hand sorting method to identify the earthworm species that voided the casts. Photographs of the casts were also taken by digital camera. The surrounding soils (non-ingested) of the casts were also collected from the quadrats (0 – 15 cm depth) with a metal shovel to compare their nutrient contents with those of the casts. Collected casts and the surrounding soils were air-dried for 1 month for nutrient analysis. For morphometric studies [height (mm) and diameter (mm) of casts], 10 individual casts per species were considered. Using a digital soil thermometer, soil temperature (°C) was measured at the 15 cm depth. Annual cast production was calculated on the basis of average masses of casts from total monthly collection (dry weight g m^{-2} $month^{-1}$) followed by conversion of data to tonnes ha^{-1} $year^{-1}$.

2.3 Analysis of Casts and Surrounding Soil

Dried earthworm casts and surrounding soil samples were ground with mortar and pastle and sieved with 2 mm sieve for chemical analysis such as soil pH [1:2.5 (Soil: Water) dilution method], soil organic carbon (organic C) by Walkley and Black [22] rapid titration method, total nitrogen (total N) by Kjeltec method [23], available phosphorus (av. P) by Bray and Kurtz method [24] and available potassium (av. K) by Flame photometer method [23]. Moisture (%) of cast and its surrounding soils was determined by the gravimetric wet weight method. Variations in the physicochemical parameters of casts and surrounding soils were tested by Student's t-test by using STAT PEARL software. The correlation coefficient (r) was applied to evaluate the relationships between rainfall vs. cast production and soil physical properties (temperature and moisture) vs. cast production.

3. RESULTS AND DISCUSSION

During our present study casts of 9 earthworm species (*Eutyphoeus assamensis*, *E. comillahnus*, *E. scutarius*, *E. gigas*, *Lampito mauritii*, *Kanchuria* sp., *Metaphire houlleti*, *Pontoscolex corethrurus* and *Glyphidrilus* sp.) were recorded from three land-use systems (pasture, natural forest and rubber plantation) (Fig. 1). Out of 9 earthworm species, 7 species were endogeic (*E. assamensis*, *E. comillahnus*, *E. scutarius*, *E. gigas*, *Kanchuria* sp., *P. corethrurus* and *Glyphidrilus* sp.) and 2 species (*L. mauritii* and *M. houlleti*) of the anecic category. Among them, surface casting activity of 2 earthworm species (*L. mauritii* and *Glyphidrilus* sp.) were restricted to pasture soils, while casting activity of *E. scutarius* and *E. gigas* were observed only in the natural forest. Interestingly, surface casting of only 4 earthworm species (*P. corethrurus*, *Kanchuria* sp., *M. houlleti*, *E. comillahnus*) were observed in the rubber plantation. Most of the surface casts were produced by the family Octochaetidae (*E. assamensis*, *E. comillahnus*, *E. scutarius,* and *E. gigas*) which were followed by Megascolecidae (*L. mauritii*, *Kanchuria* sp. and *M. houlleti*), Glossoscolecidae (*P. corethrurus*) and Almidae (*Glyphidrilus* sp.).

3.1 Morphometric Study of Earthworm Casts

Morphometric details of 9 earthworm species and their casts are presented in Table 1. Earthworm species such as *E. gigas* and *E. scutarius* egested tower-like surface casts with compact tubular convolutions. Thick tubular convolution forms were observed in the casts of *E. assamensis*. Fragile soil aggregates with or without convolutions were produced by *E. comillahnus*. *L. mauritii* voided small heaps along with spheroidal or oval pellets. Casts were large globoid mounds in case of *Kanchuria* sp. Large tower-like casts of *M. houlleti* consists of a regular arrangement of spherical or sub-spherical soil aggregates. Composite casts with irregular shape were produced by *P. corethrurus*. Small composite tubular convolutions in 'small heap' form were deposited by *Glyphidrilus* sp. Different species of earthworms deposit casts of different shapes and sizes. The difference in the shape and size of casts was probably due to differences in the anal morphology of earthworms [25]. There was a strong positive correlation observed between the body weight of earthworm species and their cast diameter ($r = 0.68$, $P = 0.01$) during our present study. Among the studied earthworm species, large earthworm species such as *E. gigas* produced large casts (55-74 mm × 40-50 mm) followed by *E. scutarius* (35-77 mm × 20-38 mm) and *M. houlleti* (27-77 mm × 15-37 mm). On the other hand, small earthworms like *Glyphidrilus* sp., *P. corethrurus* and *L. mauritii* produced smaller casts. Chaudhuri et al. [26] also reported a positive relationship between earthworm body weight and the size of casts found in rubber plantations of Tripura, India.

Fig. 1. Showing casts of different earthworm's species (9 earthworm species) found from three studied systems (pasture, natural forest and rubber plantation)

3.2 Production of Earthworms Casts under Pasture, Natural Forest and Rubber Plantation

Annual cast productions under pasture, natural forest and rubber plantations were 11.16 tonnes ha^{-1} $year^{-1}$, 23.44 tonnes ha^{-1} $year^{-1}$ and 9.92 tonnes ha^{-1} $year^{-1}$ respectively. From Table 2 it is evident that cast production by earthworms in tropical regions ranges from 3.9 to 222.3 tonnes ha^{-1} $year^{-1}$. So, the annual cast production under the present studied systems is well within the reported range. However, a good number of earthworm species voided sub-surface casts so the actual amount of soil turn-over by earthworms may be even greater [27].

Among the 9 earthworm species, *L. mauritii* contributed the highest cast production (5.00 tonnes $ha^{-1}year^{-1}$) under pasture ecosystems, whereas, *E. assamensis* (8.44 tonnes $ha^{-1}year^{-1}$) and *P. corethrurus* (6.65 tonnes $ha^{-1}year^{-1}$) were the major contributors under the natural forest and the rubber plantation respectively (Fig. 2). However, production values in the natural forest between *E. assamensis* and *Kanchuria* sp. were close. Interestingly, Chaudhuri et al. [26] also observed a good amount of cast production throughout the year under rubber plantations of Tripura, India due to more than 70% of the relative density of *P. corethrurus*, an exotic earthworm with wide ecological tolerance.

Variations in the amount of casts production during different seasons is a good index of earthworm activity [17]. An increase in earthworm cast production was recorded from July to October that coincides with monsoon. Similar findings were also reported by Bhadauria and Ramakrishnan [31] (pine forests in the north-eastern region of India), Chaudhuri et al. [26] (rubber plantations, Tripura, India), and Lalthanzara and Ramanujam [16] (agroforestry systems of Mizoram, India). Among the studied sites, pasture had a peak of cast production during September in 2017 and August 2018. On the other hand, the natural forest had its peak of cast production during August in 2017 and July 2018. Rubber plantation had peak of earthworm cast production in August during both the two years (2017-2018) (Fig. 3). Natural forest showed significant ($P < .05$) higher seasonal cast production (g m^{-2}) compared to pasture and rubber plantation during Summer (pasture: 56.47±5.14, natural forest: 105.95±10.19, rubber plantation: 48.01±6.01) and Monsoon (pasture: 138.84±8.91, natural forest: 299.05±16.39, rubber plantation: 118.89±5.86). During winter natural forest showed a significant difference ($P < .05$) in cast production compared to rubber plantation (natural forest: 76.48±23.82, rubber plantation: 20.21±5.10) but the difference was not significant ($P > .05$) with that of pasture (36.95±8.38). However, pasture and rubber plantation showed no significant difference ($P > .05$) in cast production throughout the three seasons. According to Kale and Karmegam [32], Goswami [33] cast production in tropical countries is restricted to wet seasons. Moreover, the quantity of earthworm casting depends on the suitability of the habitat such as vegetation, soil moisture, temperature, texture etc. [34, 35].

Table 1. Morphometric parameters of the 9 earthworm species and their casts

Earthworm species	Habitat	Size of earthworm [length (mm) × diameter (mm)]	Fresh body weight (mg)	Shape of casts	Size of casts [height (mm) × diameter (mm)]
Kanchuria sp.	P, NF, RP	160-360 × 3-5	1200-2280	Large globoid aggregates	22-44 × 18-40
M. houlleti	P, NF, RP	61-175 × 3-4	1270-4250	Tower like, presence of spherical or sub-spherical soil aggregates	27-77 × 15-37
E. comillahnus	P, NF, RP	71-180 × 3-4	520-2100	Soil aggregates with medium convolutions	35-57 × 25-30
P. corethrurus	P, NF, RP	48-110 × 1-3	330-560	Composite cast, irregular in shape	12-20 × 10-14
E. assamensis	P, NF	137-350 × 4-6	2010-7120	Tubular convolution	25-55 × 15-40
L. mauritii	P	70-181 × 3-4	380-1080	Spheroidal or oval pellets	10-18 × 9-15
Glyphidrilus sp.	P	100-110 × 2-3	180-540	Small heap of little convolutions	12-17 × 9-14
E. scutarius	NF	224-328×5-7	3040-6330	Tower like with compact convolutions	35-77×20-38
E. gigas	NF	120-190×5-8	1280-3840	Tower like with compact convolutions	55-74×40-50

**P- Pasture, NF- Natural forest, RP- Rubber plantation*

Table 2. Earthworm cast production (tonnes ha^{-1} $year^{-1}$) in various sites of the world

Location	Vegetation	Cast production (tonnes ha^{-1} $year^{-1}$)	Reference
India	Pasture	11.16	Present study
India	Natural forest	23.44	Present study
India	Rubber plantation	9.92	Present study
India	Bamboo plantation	42.62	[28]
India	Rubber plantation	24	[26]
India	Mixed forest	21.3	[26]
India	Mixed woodland	23.4-140.9	[20]
India	Grassland	76.8	[19]
India	Grassland	3.9-77.8	[17]
Ivory Coast	Savannah	507.0	[29]
Japan	Pasture	38.0	[30]
Nigeria	Grassland	173.0-222.3	[18]

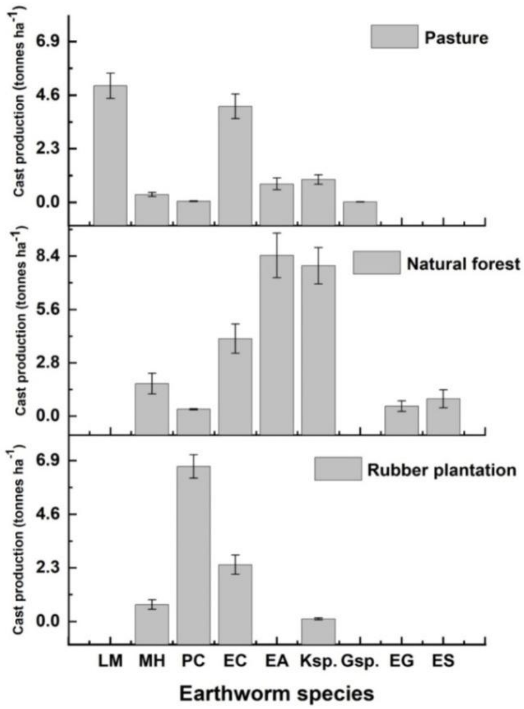

Fig. 2. Species wise cast production under pasture, natural forest and rubber plantation (LM= *Lampito mauritii*, MH= *Metaphire houlleti*, PC= *Pontoscolex corethrurus*, EC= *Eutyphoeus comillahnus*, EA= *E. assamensis*, Ksp.= *Kanchuria* sp., Gsp.= *Glyphidrilus* sp., EG= *E. gigas*, ES= *E. scutarius*)

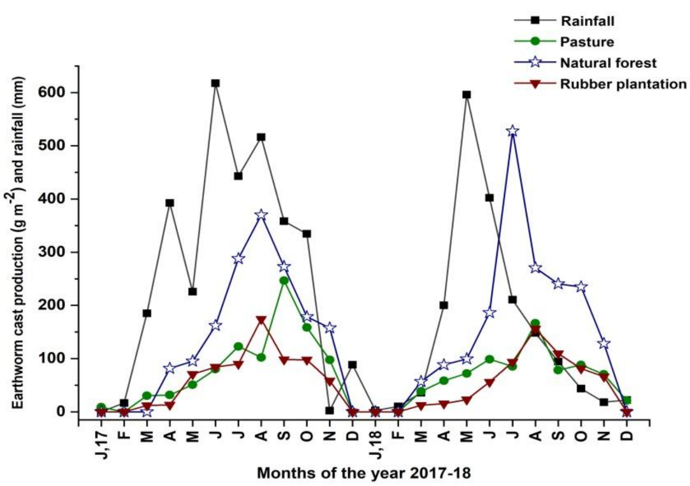

Fig. 3. Showing month-wise variation in the cast production in relation to rainfall in the pasture, natural forest and rubber plantation

3.3 Relationship between Earthworm Cast Production and Environmental Factors

Cast production in earthworms had a good positive correlation with rainfall (pasture: r = 0.59, $P < .05$; natural forest: r = 0.48, $P < .05$; rubber plantation: r = 0.69, $P < .05$), soil temperature (pasture: r = 0.51, $P < .05$; natural forest: r = 0.54, $P < .05$; rubber plantation: r = 0.52, $P < .05$), soil moisture (pasture: r = 0.59, $P < .05$; natural forest: r = 0.62, $P < .05$; rubber plantation:

r = 0.66, P < .05) under the three studied land-use systems (Fig. 4). Positive correlation between cast production and each of factors such as rainfall, soil temperature and moisture suggest that land-use pattern, as well as, environmental factors have great influence on the earthworms cast productions [6, 36]. According to Chakraborty et al. [28], Tripura belongs to a high rainfall (2000 mm/year) zone, which helps in soil moisture retention for a considerable period of time that leads to casts availability near the end of the year. Weak negative correlation was observed between earthworms cast production and soil organic C (pasture: r = -0.28, P = 0.23; natural forest: r = -0.29, P = 0.26; rubber plantation: r = -0.25, P = 0.43). This result is in agreement with the observations of Chaudhuri et al. [26] under rubber plantations in Tripura, India and indicates earthworms in organic carbon poor soils produce more amounts of casts than the soils rich in carbon [37].

3.4 Characteristics of Earthworm Casts and Surrounding Soils

Data in Table 3 clearly indicates that earthworm casts had significantly (P < .05) higher pH value (except *P. corethrurus* under pasture ecosystems) and moisture compared to the surrounding soils under the studied habitats. Chakraborty et al. [28] also recorded higher pH and moisture (%) in earthworms casts compared to their surrounding soils of bamboo plantations in Tripura, India. The higher pH of worm casts could be due to ammonia secretion into the worm's gut or the action of calcium carbonate secreted from calciferous glands into the intestine [5]. Casts of *Glyphidrilus* sp. and *E. assamensis* showed the highest moisture retention of 49.79% and 41.65% under pasture respectively. *E. gigas* had highest moisture retention (41.39%) in their casts found in natural forests, followed by *M. houlleti* (39.18%). Under rubber plantation highest moisture retention was observed in the casts of *E. comillahnus* (52.02%) and *Kanchuria* sp. (50.86%) compared to their surrounding soils. Significantly higher moisture retention in the earthworm casts was probably due to the availability of more organic carbon, as well as, abundant micropores and a specific surface area promotes more moisture accumulation [38].

Analysis of chemical properties of 9 species of earthworm casts and their surrounding soils revealed that casts contain significantly (P < .05) greater proportions of organic C (g%) under pasture, natural forest and rubber plantations (Table 3). It may be due to the addition of intestinal mucus during the gut and cast associated processes and also selective feeding of organically richer soil fractions by earthworms [5]. According to Bossuyt et al. [39] binding agents present in the mucus of earthworms bind organic and mineral particles together which protects soil carbon from rapid degradation. Similar results have also been reported by Bisht et al. [40] and Chaudhuri et al. [26]. Increase in organic carbon in the casts compared to the surrounding soils was found to be much higher in case of *E. comillahnus* (2.16 times) in pasture, *Kanchuria* sp. (2.38 times), *E. comillahnus* (2.34 times) in rubber plantation and *M. houlleti* (2.28 times) under natural forest. However, casts of *M. houlleti* in pasture soils and *P. corethrurus* under natural forests showed no significant difference in organic C compared to their surrounding soils. This is probably because of greater efficiencies in the carbon assimilation of these species [6].

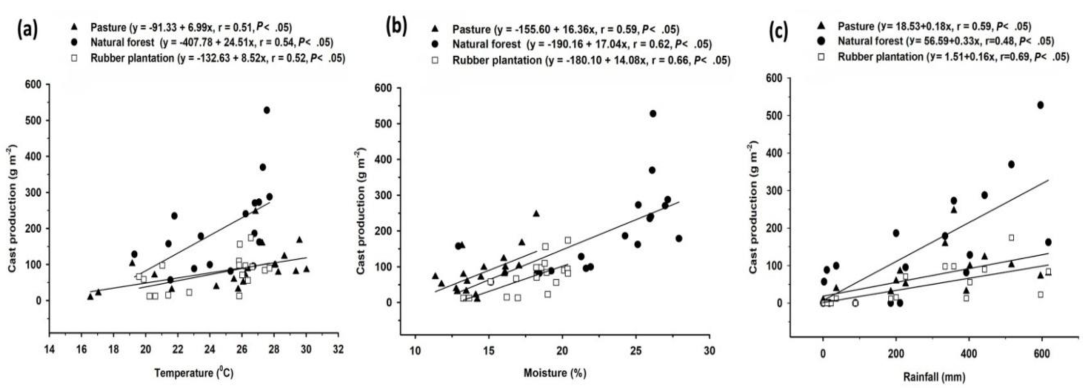

Fig. 4. Showing linear regression analysis between – (a) earthworm cast productions vs. soil temperature, (b) earthworm cast productions vs. soil moisture and (c) earthworm cast productions vs. rainfall

Table 3. Physicochemical properties of casts of 9 earthworm species and their surrounding soil (n=3) under the three studied systems

Earthworm species ➡		*Kanchuria* sp.		*M. houlleti*		*E. comillahnus*		*P. corethrurus*		*E. assamensis*		*L. mauritii*		*Glyphidrilus* sp.		*E. scutarius*		*E. gigas*	
Parameters	**Habitat**	**Soil**	**Cast**	**Soil**	**Cast**	**Soil**	**Cast**	**Soil**	**Cast**	**Soil**	**Cast**	**Soil**	**Cast**	**Soil**	**Cast**	**Soil**	**Cast**	**Soil**	**Cast**
pH	P	5.37 ±0.06^{a}	5.79 ±0.09^{b}	5.24 ±0.06^{a}	5.48 ±0.07^{b}	5.28 ±0.13^{a}	5.62 ±0.02^{b}	5.43 ±0.1^{a}	5.49 ±0.09^{a}	5.48 ±0.07^{a}	5.88 ±0.09^{b}	5.44 ±0.11^{a}	6.02 ±0.07^{b}	5.66 ±0.02^{a}	5.95 ±0.08^{b}				
	NF	4.99 ±0.06^{a}	5.5 ±0.17^{b}	5.18 ±0.12^{a}	5.61 ±0.04^{b}	5.38 ±0.03^{a}	5.79 ±0.09^{b}	5.31 ±0.11^{a}	5.74 ±0.04^{b}	4.94 ±0.05^{a}	5.03 ±0.04^{b}					5.48 ±0.02^{a}	5.84 ±0.07^{b}	5.53 ±0.1^{a}	5.83 ±0.04^{b}
	RP	4.84 ±0.09^{a}	5.29 ±0.03^{b}	4.82 ±0.10^{a}	5.49 ±0.03^{b}	4.44 ±0.03^{a}	5.7 ±0.03^{b}	4.75 ±0.05^{a}	5.8 ±0.02^{b}										
Moisture (%)	P	15.58 ±1.49^{a}	36.13 ±3.00^{b}	18.63 ±1.94^{a}	28.41 ±2.35^{b}	13.03±1.03^{a}	38.71±3.30^{b}	17.35 ±0.42^{a}	36.46 ±4.33^{b}	12.81 ±0.58^{a}	41.65 ±3.91^{b}	12.55 ±0.74^{a}	35.12 ±3.34^{b}	28.20 ±0.16^{a}	49.79 ±1.44^{b}				
	NF	21.48 ±1.05^{a}	35.39 ±1.53^{b}	22.9 ±1.36^{a}	39.18 ±3.09^{b}	22.97±1.25^{a}	34.97±3.46^{b}	14.85 ±0.51^{a}	22.76 ±0.9^{b}	18.25 ±0.77^{a}	36.04 ±1.27^{b}					20.47 ±0.78^{a}	34.25 ±4.83^{b}	21.24 ±0.75^{a}	41.39 ±3.28^{b}
	RP	18.7 ±0.59^{a}	50.86 ±5.97^{b}	20.91 ±1.76^{a}	48.28 ±4.67^{b}	18.39±0.42^{a}	52.02±3.70^{b}	19.54 ±0.39^{a}	42.73 ±3.96^{b}										
Organic C (g%)	P	0.55 ±0.09^{a}	1.04 ±0.14^{b}	0.72 ±0.14^{a}	0.82 ±0.06^{a}	0.50 ±0.03^{a}	1.08 ±0.06^{b}	0.54 ±0.07^{a}	0.94 ±0.12^{b}	0.67 ±0.10^{a}	1.31 ±0.20^{b}	0.64 ±0.02^{a}	0.89 ±0.02^{b}	0.69 ±0.02^{a}	1.26 ±0.05^{b}				
	NF	0.76 ±0.05^{a}	1.04 ±0.06^{b}	0.82 ±0.03^{a}	1.87 ±0.21^{b}	1.11 ±0.01^{a}	2.03 ±0.06^{b}	0.73 ±0.01^{a}	0.84 ±0.06^{a}	0.85 ±0.02^{a}	1.48 ±0.07^{b}					0.76 ±0.04^{a}	1.42 ±0.07^{b}	1.03 ±0.08^{a}	1.67 ±0.02^{b}
	RP	0.69 ±0.03^{a}	1.64 ±0.08^{b}	0.82 ±0.11^{a}	1.37 ±0.10^{b}	0.76 ±0.10^{a}	1.78 ±0.10^{b}	0.72 ±0.06^{a}	1.17 ±0.11^{b}										
Total N (%)	P	0.09 ±0.01^{a}	0.15 ±0.01^{b}	0.07 ±0.01^{a}	0.13 ±0.01^{b}	0.08 ±0.01^{a}	0.13 ±0.01^{b}	0.09 ±0.01^{a}	0.15 ±0.02^{b}	0.08 ±0.01^{a}	0.16 ±0.03^{b}	0.08 ±0.01^{a}	0.10 ±0.02^{a}	0.08 ±0.01^{a}	0.22 ±0.02^{b}				
	NF	0.13 ±0.01^{a}	0.21 ±0.02^{b}	0.13 ±0.01^{a}	0.27 ±0.02^{b}	0.14 ±0.01^{a}	0.29 ±0.02^{b}	0.11 ±0.01^{a}	0.14 ±0.01^{a}	0.12 ±0.01^{a}	0.23 ±0.01^{b}					0.12 ±0.01^{a}	0.22 ±0.02^{b}	0.15 ±0.02^{a}	0.22 ±0.02^{b}
	RP	0.13 ±0.01^{a}	0.21 ±0.02^{b}	0.11 ±0.01^{a}	0.21 ±0.01^{b}	0.14 ±0.01^{a}	0.22 ±0.01^{b}	0.12 ±0.01^{a}	0.19 ±0.01^{b}										
Av. P (kg/ha)	P	0.79 ±0.56^{a}	5.16 ±0.13^{b}	2.78 ±0.45^{a}	5.73 ±0.16^{b}	0.99 ±0.35^{a}	8.16 ±0.07^{b}	2.18 ±0.84^{a}	32.27 ±0.22^{b}	4.03 ±0.36^{a}	21.64 ±0.32^{b}	2.64 ±0.4^{a}	28.69 ±0.2^{b}	3.4 ±0.38^{a}	38.50 ±0.20^{b}				
	NF	1.85 ±0.40^{a}	16.79 ±0.27^{b}	1.98 ±0.45^{a}	7.06 ±0.16^{b}	1.68 ±0.34^{a}	21.81 ±0.23^{b}	1.27 ±0.07^{a}	12.91 ±0.20^{b}	1.50 ±0.24^{a}	6.50 ±0.31^{b}					2.27 ±0.31^{a}	12.08 ±0.16^{b}	1.85 ±0.51^{a}	33.58 ±0.31^{b}
	RP	4.95 ±0.24^{a}	22.42 ±0.23^{b}	6.73 ±0.46^{a}	18.44 ±0.19^{b}	5.56 ±0.38^{a}	23.26 ±0.23^{b}	5.95 ±0.76^{a}	15.55 ±0.36^{b}										
Av. K (kg/ha)	P	400.45 ±0.77^{a}	1406.43 ±0.61^{b}	249.70 ±7.61^{a}	330.98 ±0.55^{b}	301.36±0.80^{a}	1192.50 ±0.37^{b}	250.46 ±0.77^{a}	550.32 ±0.72^{b}	397.70 ±0.96^{a}	1220.82 ±0.47^{b}	264.46 ±0.56^{a}	300.18 ±0.47^{b}	311.01 ±1.14^{a}	712.18 ±0.19^{b}				
	NF	713.57 ±0.69^{a}	897.03 ±0.58^{b}	651.63 ±0.81^{a}	1988.85±1.07^{b}	653.55±0.68^{a}	1841.65 ±0.97^{b}	295.48 ±0.86^{a}	3055.65±0.61^{b}	298.80 ±0.24^{a}	691.83 ±0.34^{b}					636.47 ±0.76^{a}	1506.34 ±1.63^{b}	436.96 ±1.18^{a}	1727.59 ±3.24^{b}
	RP	236.97 ±1.10^{a}	448.86 ±0.34^{b}	230.57 ±0.75^{a}	445.82 ±0.40^{b}	299.79±1.24^{a}	452.01 ±0.43^{b}	253.89 ±1.23^{a}	429.87 ±0.21^{b}										

**Same letter (a, a) correspond to no significant difference at 5% level of significance [P- Pasture, NF- Natural forest, RP- Rubber plantation]*

Table 4. Showing C:N ratios of casts of 9 studied earthworm species and their surrounding soils (n=3; mean values from pasture, natural forest and rubber plantation)

Earthworm species	Habitat	C:N ratio		% of increase or decrease
		Surrounding soil	Cast	
Kanchuria sp.	P, NF, RP	6.92±0.34[a]	6.27±0.43[a]	-9.39
M. houlleti	P, NF, RP	7.38±1.17[a]	6.58±0.42[a]	-10.84
E. comillahnus	P, NF, RP	5.86±0.44[a]	8.56±0.62[b]	46.25
P. corethrurus	P, NF, RP	6.67±0.10[a]	5.95±0.57[a]	-10.79
E. assamensis	P, NF	8.01±0.86[a]	7.77±1.23[a]	-3.00
L. mauritii	P	8.13±0.34[a]	10.96±0.39[b]	34.81
Glyphidrilus sp.	P	8.7±0.63[a]	5.69±0.26[b]	-34.59
E. scutarius	NF	6.30±0.64[a]	6.61±0.43[a]	4.92
E. gigas	NF	6.86±0.90[a]	6.46±0.76[a]	-5.83

**Different letter (a, b) corresponds to a significant difference at a 5% level of significance [P- Pasture, NF- Natural forest, RP- Rubber plantation]*

Earthworm casts observed under pasture, natural forest and rubber plantations showed significantly ($P < .05$) higher values of total N (%), av. P (kg/ha) and av. K (kg/ha) (Table 3). In our present study casts rich in nitrogen support the findings of Dash and Patra [41], Krishnamoorthy [42] who also found that earthworm casts had higher nitrogen content than adjacent soils. Among the casts of 9 earthworm species, that of *Glyphidrilus* sp. in pasture and *M. houlleti* in both natural forest and rubber plantation showed 2.75, 2.08 and 1.91 times more increase in total N respectively. The increase in nitrogen content was probably due to intimate mixing of plant remains, mucoproteins secreted from the body wall of the earthworms and microbial excretions during gut and cast associated processes [5]. Although in the casts of *L. mauritii* in pastures and *P. corethrurus* under natural forest, total N marginally increased compared to its surrounding soils but the change was not significant. A significant increase in av. P in the casts than that of surrounding soils is also supported by the results of Chaudhuri et al. [26]. Comparatively higher amounts of av. P was found in the casts than the surrounding soils of *E. gigas* (18.15 times), *E. comillahnus* (12.98 times) under natural forest, *P. corethrurus* (14.80 times) in pasture and *Kanchuria* sp. (4.53 times) in rubber plantation. It has been attributed due to the excretion and decomposition by the earthworms, as well as, enhanced phosphatase activities in the casts [42-44]. On the other hand, increase in av. K observed in the casts of earthworms studied such as 3.96 times increase in *E. comillahnus* in pasture, 10.34 times increase in *P. corethrurus* in natural forest and 1.93 times more in casts of *M. houlleti* in rubber plantation may be due to their selective feeding on food materials enriched with this cation [6].

C:N ratios (n=3, combined values from pastures, natural forest and rubber plantation) in the studied casts of 9 earthworm species are presented in Table 4. Casts of 2 earthworm species, *L. mauritii* and *E. comillahnus* showed a significant ($P < .05$) increase in the C:N ratios compared to their non-ingested soils i.e. 34.81% and 46.25% of increase respectively. Though, in case of *E. scutarius* casts the increase of C:N ratio (4.92%) was not significant ($P > .05$). On the other hand casts of *Kanchuria* sp., *M. houlleti*, *E. assamensis*, *E. gigas*, *P. corethrurus,* and *Glyphidrilus* sp. had a lower C:N ratio compared to surrounding soils. However, the change was not significant ($P > .05$), except in *Glyphidrilus* sp. Anecic earthworm, *L. mauritii* showed a higher C:N ratio of 10.96, whereas the lowest C:N ratio was observed in the casts of endogeic earthworm, *Glyphidrilus* sp. (5.69). Several studies have reported that earthworm casts had a higher C:N ratio than non-ingested soils [5, 45, 46]. Meanwhile, Syers and Springett [47] reported a lower C:N ratio in the surface casts than the surrounding soil. So, the difference in the C:N ratio between casts and surrounding soils may depend on proportional utilization of C by the organism after the soil passed through the gut or soil properties of the habitat [48].

4. CONCLUSION

Following feeding on soils, earthworms produce egesta which are called casts. There are different forms of casts which are often species specific. Casts of 9 earthworm species from pasture, natural forest and rubber plantation were studied. Cast production in *L. mauritii* and *Glyphidrilus* sp. were restricted to pasture ecosystem. *E. scutarius* and *E. gigas* produced casts only under natural forest. Rubber ecosystem had surface casting of only 4 earthworm species (*P. corethrurus*, *Kanchuria* sp., *M. houlleti*, *E. comillahnus*). Species wise differences in cast productions were recorded under different land-use systems. Natural forest had the highest annual earthworm cast production (23.44 tonnes ha^{-1} $year^{-1}$) with least contribution of 0.36 tonnes ha^{-1} $year^{-1}$ by *P.*

corethrurus to highest contribution by *Kanchuria* sp. (7.89 tonnes $ha^{-1}year^{-1}$) and *E. assamensis* (8.44 tonnes $ha^{-1}year^{-1}$). On the other hand, *L. mauritii* contributed the highest (5.00 tonnes $ha^{-1}year^{-1}$) and *Glyphidrilus* sp. the lowest (0.02 tonnes ha^{-1} $year^{-1}$) cast production in pasture ecosystems with annual cast production of 11.16 tonnes ha^{-1} $year^{-1}$. *P. corethrurus* with cast production of 6.65 tonnes $ha^{-1}year^{-1}$ was the major contributor and *Kanchuria* sp. was the least contributor (0.11 tonnes ha^{-1} $year^{-1}$) under the rubber plantation with annual cast production of 9.92 tonnes ha^{-1} $year^{-1}$. In general, pH, moisture, organic C, total N, av. P and av. K were significantly higher (P < .05) in casts than the surrounding soils. The amount of cast production in different land-use systems (pasture, natural forest and rubber plantations) strongly correlate (P < .05) with soil moisture (pasture: r = 0.59, natural forest: r = 0.62, rubber plantation: r = 0.66), temperature (pasture: r = 0.51, natural forest: r = 0.54, rubber plantation: r = 0.52) and pattern of rainfall (pasture: r = 0.59, natural forest: r = 0.48, rubber plantation: r = 0.69). Percent of increase or decrease in C:N ratios between surrounding soils and casts in earthworm species indicate that *M. houlleti*, *Glyphidrilus* sp., *P. corethrurus* etc. possesses high C assimilation power than *E. comillahnus* and *L. mauritii*. Due to low C assimilation power the latter two species produce organically rich casts than the former three earthworm species. As earthworm casts are water stable soil aggregates and richer in organic C, N, P and K, it may be assumed that earthworms in the studied ecosystems have important role in soil carbon sequestration and nutrient turnover.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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