Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

E-ISSN: 2320-7078
P-ISSN: 2349-6800
JEZS 2019; 7(3): 857-862

Received: 04-03-2019
Accepted: 06-04-2019

Shilpa Panjgotra
Teaching Assistant, Department of Zoology, Punjab Agricultural University, Ludhiana, Punjab, India

GK Sangha
Dean, Post Graduate Studies, Professor, Department of Zoology, Punjab Agricultural University, Ludhiana, Punjab, India

Sandeep Sharma
Assistant Soil Microbiologist, Departent of Soil Science Punjab Agricultural University, Ludhiana, Punjab, India

Correspondence
Shilpa Panjgotra
Teaching Assistant, Department of Zoology, Punjab Agricultural University, Ludhiana, Punjab, India

The impact of earthworm population and cast properties in the soils of wheat fields in different regions of Punjab

Shilpa Panjgotra, GK Sangha and Sandeep Sharma

Abstract
The aim of the present study was to describe the potential influence of earthworm abundance on soil properties and to investigate the available nutrients present in earthworm casts in comparison to surrounding soil in different regions of Punjab viz., Amritsar, Shaheed Bhagat Singh Nagar and Moga. On average, at all sites, significantly more nutrients were available in earthworm casts as compared to surrounding soils. Among three sites, maximum significant results were obtained at Shaheed Bhagat Singh Nagar where earthworm population was more and contained higher content of nitrogen, phosphorous, potassium, organic carbon and optimum levels of pH and EC (electrical conductivity) in casts as compared to surrounding soil. Earthworm abundance and nutrient availability was maximum in the month of March, this correlates with earthworm population. The study indicates that earthworms and earthworm castings are valuable nutrient sources for plants and can improve the physical and chemical properties of the soil.

Keywords: Earthworm casts, physico-chemical properties, soil fertility, soil properties, surrounding soil, earthworm population

Introduction
Protection and conservation of the soil habitat is the first step towards sustainable management that determines its long term quality and productivity. Usually it is accepted that soil biota benefits soil productivity and fertility but very little is known about the organisms that live in soil as well as their role in the functioning of the soil ecosystem [1]. Earthworms are the large megadrile annelids of the class Oligochaeta that constitutes more than 80% of soil invertebrate biomass in terrestrial ecosystems [2]. India is a diverse country harbouring a very high diversity of earthworms, which mostly concentrated in Western Ghats and Eastern Himalayas both of which are recognized as biodiversity 'hot spots'. Although this area is only 2% of the world's land mass, it supports about 105 per cent of the total known global earthworms, estimated around 4000 species. Predominantly the Indian earthworm fauna is composed of native species, which constitute about 89% of total earthworm diversity in the country [3].
Earthworms are considered as one of the most important group of soil engineers [4, 5]. They make to form the major group of soil invertebrates in tropical, sub-tropical and temperate zones [6]. Earthworms play a prominent and significant role in creating heterogeneous patterns in ecosystems, mostly by displacing soil organic and mineral compounds from one site to another, and by producing biogenic structures, i.e. organo-mineral aggregates (faeces, burrows, etc.), with specific type of physical, chemical and biological properties [7, 8].
The nutrient cycling is a critical function of ecosystem which is essential for life on earth [9]. Earthworms feed on soil along with on a wide range of decaying organic substances, and excrete waste in the form of casts. The castings egested by earthworms have normaly been assumed to be more stable and fertile than the parent soil aggregates and contain certain enzymes, microorganisms, hormones, inorganic and organic materials which it acquires during the passage of digestion through the earthworm gut [10]. The earthworm gut contains many endogenic and exogenic enzymes to convert organic minerals into more exchangeable and available forms to plants [11]. The production of casts in earthworm is an indicator of burrowing and soil turnover because 99.9 % of ingested material is egested as castings [12].
The presence of earthworms in the field is generally associated with the formation of water stable biogenic aggregates, i.e. the casts, where a significant proportion of soil organic matter

(SOM) is physically and chemically protected which is further stabilized [13, 14]. In cultivated soils, where organic matter is frequently related to fertility and productivity, the invertebrate community especially earthworms play an significant role in soil organic matter dynamics by regulating the processes of humification and mineralization [15]. Earthworm casts and burrow linings contain more extractable nutrients than the parent surrounding soil [16]. They are important agents in many tropical and temperate ecosystems in regulating soil organic matter, nutrient cycling processes and through their activities in soils they even create new habitat for other organisms [17]. Most of the studies conducted, to access the role of earthworm castings in nutrient cycling and soil structure are related to surface casting species and only a few have dealt with casts deposited under field condition [17]. The present study was carried out to examine, the relationship of earthworms on physicochemical properties of surface casts in wheat fields of Punjab. The study also compared the properties of surrounding soil with the earthworm biogenic structures.

Materials and Methods

Study site: The study was conducted in different regions of Punjab. The study area was representative of Majha (Amritsar), Doaba (Shaheed Bhagat Singh (SBS) Nagar) and Malwa (Moga) regions of Punjab. Sampling was done minimum in three villages from each district and three fields from each village. The villages and fields were randomly selected from each district. Randomly selected villages from different districts are Amritsar (village I - Kohali**,** village II - Loharka kalan**, v**illage III - Sohian kalan), SBS Nagar (village I - Attari, village II - Renewal**,** village III – Dupalpur), Moga **(**village I - Rouke**,** village II – Himmatpura, village III - Jaimal wala).

Earthworm and casts collection: Earthworm and casts sampling was carried out in wheat growing districts of Punjab [Amritsar, Shaheed Bhagat Singh Nagar (SBS Nagar) and Moga] during November 2014 to April 2015. Sampling was done minimum in three villages from each district. Three fields were randomly selected from each village. Earthworm and casts sampling was carried out every month from each village in wheat growing fields. Earthworms were removed by hand-sorting and preserved in formalin solution for 2 days and then transferred to 70% alcohol. The presence or absence of earthworm casthills on the soil surface was scored for the studied area. Casts were collected, air-dried and weighed. The surrounding soil was also sampled without casthills. 100g of surrounding soil and cast samples was collected from the study area for analysis.

Physico-chemical Analysis: The physicochemical parameters of the earthworm casts and surrounding soil were analysed using standard methods. The pH and electrical conductivity (EC) was determined using a double distilled water suspension in the ratio of 1:2 (w/v) and measured using digital pH and EC meter. Organic carbon (OC) content was determined by partial oxidation method (Walkey and Black, 1934). Total kjeldahl nitrogen was measured by the method as described by Jackson (1958). Phosphorus was analysed with molybdenum in sulphuric acid by $NaHC0_3$ (Sodium hydrogen carbonate) method (Olsen *et al*., 1954). Ammonium acetate exchangeable potassium was determined by using flame photometer.

Statistical Analysis: Data was expressed as mean±S.E. Differences in the physico-chemical properties of surrounding soil and earthworm casts was compared using student's t-test. A significant level of $p<0.05$ was considered throughout the analysis.

Results

Earthworm Abundance

Comparison of the earthworm abundance in different districts is shown in table 1. Earthworm population varied with variation in the edaphic factors of different regions. Total earthworm population was maximum at Shaheed Bhagat Singh Nagar (446), followed by Amritsar (336) and least in Moga (202). Analysis of monthly differences of earthworm abundance at all the study sites in wheat fields showed that the earthworm population was maximum in the month of March. However, the lowest average of earthworm abundance at all the study areas was observed in November when moisture decreased and temperature increased. Earthworm individuals were not found in the month of December and January when temperature and moisture conditions of soil are not favourable for earthworm survival.

Table 1: Earthworm population (from each district) in wheat growing fields in different regions of Punjab

Months	Amritsar	SBS Nagar	Moga
November	54	56	40
December	0	0	0
January	0	0	0
February	65	83	52
March	146	167	69
April	71	140	41
Total	336	446	202

Physical and Chemical properties of earthworm casts and surrounding soil in different studied areas:

During the study period, it was found that there was decrease in physical properties such as pH, EC (electrical conductivity) and increase in chemical properties such as nitrogen, phosphorous, potassium and organic carbon in the earthworm casts as compared to surrounding soil. The pH shows non-significant result while EC, Nitrogen, phosphorus, potassium and organic carbon content differed significantly ($p<0.05$) in the earthworm casts as compared to surrounding soil in different regions of Punjab (Table 2 and 3). The pH level decreased throughout the study period in earthworm casts as compared to surrounding soil in all the studied districts. In earthworm casts the lowest pH and EC was observed in the month of March. On an average decrease in pH from surrounding soil to earthworm casts was 7.51±0.04 to 7.34±0.07 at Amritsar, 7.41±0.04 to 7.32±0.04 at SBS Nagar and 7.50±0.03 to
7.37±0.03 at Moga (Table 2). The EC of earthworm casts is also decreased slightly from the surrounding soil during the study period. The maximum decrease in physical properties of earthworm casts was observed in SBS Nagar followed by Amritsar and decrease was least observed in Moga. The decrease in pH was non-significant and EC shows the significant decrease. In the earthworm casts pH reached towards neutrality and EC was found to be within normal limits in all the three districts.

Availability of all the nutrients was more in earthworm casts as compared to surrounding soil and content was maximum in the month of March as compared to other months in all the

districts due to increase in earthworm population in this month. In earthworm casts the significant (p<0.05) average increase in nitrogen content at Amritsar, SBS Nagar and Moga was 166.64±1.77 kg/ha, 175.55±5.52 kg/ha and 164.84±2.87 kg/ha respectively. In different districts average percent increase in nitrogen was 21.14%, 23.43% and 22.26% respectively. Phosphorus follows the similar trend and significant (p<0.05) results were observed in earthworm casts when compared with surrounding soil. In earthworm casts with an average value maximum significant (p<0.05) results were obtained at SBS Nagar (46.87±1.90 kg/ha) followed by Amritsar (45.97±1.32 kg/ha) and was least in Moga (44.19±2.07 kg/ha). Average percent increase in phosphorus level was 43.74% (Amritsar), 43.99% (SBS Nagar) and 49.84% (Moga).

Potassium increased significantly (p<0.05) from surrounding soil to earthworm casts. Maximum increase in potassium content in earthworm casts was at SBS Nagar (172.55±5.45) and minimum was at Moga (155.93±1.77 kg/ha) and the average percent increase was 15.06% in Amritsar, 15.09% in SBS Nagar and 11.31% in Moga. Organic carbon also increased significantly (p<0.05) in the earthworm casts as compared to surrounding soil. The increase was maximum at SBS Nagar (0.75±0.02%) with an average percent increase of 38.89%.

Table 2: Physical properties of surrounding soil and earthworm casts in wheat fields from different regions of Punjab.

Months			pH						EC (dS m^{-1})			
	Amritsar		SBS Nagar		Moga		Amritsar		SBS Nagar		Moga	
	Soil	Cast	Soil	Cast	Soil	Cast	Soil	Cast	Soil	Cast	Soil	Cast
Year 2014												
November	7.54±0.02	7.48±0.01	7.52±0.04	7.40±0.07	7.56±0.02	7.43±0.02	0.62±0.01	0.54±0.01	0.57±0.03	0.49±0.02	0.64±0.06	0.55±0.04
December	7.67±0.02	0.00±0.00	7.58±0.01	0.00±0.00	7.69±0.03	0.00±0.00	0.67±0.02	0.00±0.00	0.61±0.03	0.00±0.00	0.68±0.02	0.00±0.00
Year 2015												
January	7.69±0.01	0.00±0.00	7.59±0.13	0.00±0.00	7.70±0.10	0.00±0.00	0.67±0.01	0.00±0.00	0.65±0.02	0.00±0.00	0.69±0.04	0.00±0.00
February	7.60±0.03	7.39±0.01	7.45±0.09	7.37±0.10	7.47±0.0	7.38±0.0	0.62±0.01	0.49±0.03	0.58±0.02	0.47±0.03	0.61±0.02	0.50±0.01
March	7.38±0.01	7.12±0.02	7.26±0.04	7.19±0.04	7.41±0.03	7.26±0.02	0.59±0.02	0.43±0.02	0.52±0.01	0.40±0.03	0.60±0.05	0.44±0.03
April	7.52±0.02	7.36±0.01	7.39±0.14	7.31±0.15	7.55±0.01	7.41±0.01	0.60±0.01	0.48±0.03	0.56±0.04	0.46±0.04	0.63±0.02	0.55±0.03
Average (kg/ha)	7.51±0.04	7.34±0.07	7.41±0.04	7.32±0.04	7.50±0.03	7.37±0.03	0.61±0.08	0.48±0.02*	0.61±0.01	0.45±0.01*	0.62±0.01	0.51±0.02*
Average %decrease	2.26%		1.21%		1.73%		21.31%		19.64%		17.74%	

Values are Mean±SE, the values with superscript (*) show significant difference (p<0.05) between surrounding soil and earthworm casts

Table 3: Chemical properties of surrounding soil and earthworm casts in wheat fields from different regions of Punjab

Months			Nitrogen kg/ha						Phosphorous kg/ha			
	Amritsar		SBS Nagar		Moga		Amritsar		SBS Nagar		Moga	
	Soil	Cast	Soil	Cast	Soil	Cast	Soil	Cast	Soil	Cast	Soil	Cast
Year 2014												
November	131.40±1.61	162.63±1.64	137.64±1.74	162.91±1.33	131.93±1.56	160.59±1.25	30.37±0.88	42.88±0.67	30.90±0.65	41.82±0.50	28.13±0.82	39.02±0.82
December	108.59±1.54	0.00±0.00	123.98±1.22	0.00±0.00	111.29±1.41	0.00±0.00	25.75±0.21	0.00±0.00	25.42±0.96	0.00±0.00	24.06±0.71	0.00±0.00
Year 2015												
January	107.61±1.52	0.00±0.00	121.96±1.42	0.00±0.00	110.90±1.05	0.00±0.00	23.71±0.75	0.00±0.00	23.61±0.99	0.00±0.00	23.99±0.76	0.00±0.00
February	137.09±1.34	164.70±1.74	138.72±1.86	174.97±1.79	135.26±0.80	164.78±1.22	31.65±0.70	44.78± 0.23	31.60±0.78	46.14±0.74	29.97±0.44	45.66±0.41
March	145.09±1.49	169.96±1.70	151.78±1.84	189.88±1.91	139.45±1.04	172.98±0.64	32.97±0.91	48.77±0.68	334.23±0.72	50.42±0.87	30.06±0.23	48.85±0.72
April	136.65±0.77	169.28±1.85	140.74±1.39	174.47±1.24	132.70±1.33	161.00±1.27	32.95±0.99	47.44±0.58	33.46±0.4	49.12±0.60	29.80±0.41	43.23±0.37
Average	137.56±2.82	166.64±1.77*	142.22±3.25	175.55±5.52*	134.83±1.69	164.84±2.87*	31.98±0.62	45.97±1.32*	32.55±0.77	46.87±1.90*	29.49±0.45	44.19±2.07*
Average %increase	21.14%		23.43%		22.26%		43.74%		43.99%		49.84%	
			Potassium kg/ha						Organic carbon (OC) %			
Seasons	Amritsar		SBS Nagar		Moga		Amritsar		SBS Nagar		Moga	
	Soil	Cast	Soil	Cast	Soil	Cast	Soil	Cast	Soil	Cast	Soil	Cast
Year 2014												
November	139.08±1.62	159.26±1.41	142.68±0.76	161.79±1.39	135.68±1.04	151.04±1.55	0.48±0.01	0.68±0.02	0.50±0.05	0.71±0.03	0.41±0.02	0.60±0.02
December	132.30±1.61	0.00±0.00	133.86±1.12	0.00±0.00	123.62±1.67	0.00±0.00	0.41±0.03	0.00±0.00	0.37±0.02	0.00±0.00	0.36±0.01	0.00±0.00
Year 2015												
January	129.68±1.21	0.00±0.00	135.91±1.71	0.00±0.00	123.81±1.55	0.00±0.00	0.40±0.02	0.00±0.00	0.37±0.05	0.00±0.00	0.35±0.02	0.00±0.00
February	143.40±1.39	167.67±1.17	146.75±1.26	168.37±1.29	139.29±1.19	157.04±1.11	0.47±0.02	0.71±0.04	0.51±0.02	0.73±0. 02	0.45±0.01	0.73±0.04
March	152.93±0.90	177.71±1.19	169.77±1.22	187.52±1.86	147.23±1.62	164.15±1.80	0.55±0.02	0.78±0.03	0.62±0.06	0.80±0.04	0.52±0.03	0.74±0.02
April	141.79±1.42	159.49±0.92	140.46±1.62	172.51±1.06	138.14±1.88	156.17±0.59	0.49±0.01	0.73±0.04	0.51±0.04	0.76±0.05	0.43±0.03	0.67±0.03
Average (kg/ha)	144.30±3.01	166.03±4.35*	149.92±6.74	172.55±5.45*	140.08±2.49	155.93±1.77*	0.50±0.01	0.73±0.02*	0.54±0.02	0.75±0.02*	0.45±0.02	0.68±0.03*
Average	15.06%		15.09%		11.31%		46%		38.89%		51.11%	

Values are Mean±SE, the values with superscript (*) show significant difference (p<0.05) between surrounding soil and earthworm casts

Overall the results revealed that maximum earthworm population was observed at SBS Nagar so as the nutrient availability. Nutrient content was maximum in the month of March which correlates with the earthworm population. Presence of earthworms increases the availability of nutrients and vice-versa. Nutrient levels decreased with the decrease in earthworm population. Earthworm abundance and nutrient availability follows the trend as SBS Nagar>Amritsar>Moga.

Discussion

Soil fertility can be maintained and improved by manipulating the community of earthworms in the soil habitat [19]. The

distribution and density of earthworm population have been correlated with soil type, and agricultural land use [20]. Ecological engineers like earthworms play an influential role in agro-ecosystems in maintaining soil productivity and fertility by changing the physico-chemical parameters of soil. These changes results due to reorganisation of structure of soil by movement of earthworms through soil and during gut transit [9]. Physico-chemical properties of the soil also play an significant role in maintaining earthworm biodiversity [21]. Earthworm population density and soil physic-chemical properties are positively correlated [22].

In wheat fields from all the districts of Punjab earthworm abundance was maximum in the month of March which correlates with nutrient availability. Nutrient availability decreases with earthworm population. Minimum earthworm population was observed in the month of November so as the nutrients. The results of soil analysis also revealed that earthworm containing soil have the high nutrient content as compared to the soil with less number of earthworms. The abundance and distribution of earthworms have been known to influence with both physical and organic factor of soil [23]. Nutrient dynamics of soil was significantly correlated with earthworm number in the soil habitat [21]. At all the study sites, nutrient availability was significantly higher in the presence of earthworms.

The present study showed lower pH, EC and higher nitrogen, phosphorous, potassium and organic carbon in earthworm casts as compared to surrounding soil in all the three districts of Punjab. A lower pH value in earthworm cast compared to surrounding soil observed in the present study, might be due to the difference in organic matter (OM) and Ca content [21]. Calcium and OM of certain residue are able to correct the alkalinity of cast, thus the pH of cast becomes lower. The pH value of cast soil was lower this may also be due to the ammonia secreted in the worm's gut, which further act as a neutralizing factor [24] and/or the calciferous glands produce calcium carbonate and its release into the intestine [25]. The change in pH value toward neutrality may be due to the mineralization of nitrogen and phosphorous into nitrites or nitrates and into orthophosphates [26]. Elvira *et al*., [27] reported that the joint action of earthworms and microbial decomposition lead to lower pH in the vermicast.

In the present study, EC slightly decreased in the casts when compared with surrounding soil. Soil pH and EC are interrelated. Decrease in soil pH would results in lower EC of the soil [28, 29]. This decrease in EC may be due to loss of organic matter and release of different mineral salts in available forms such as phosphate, ammonium and potassium [30]. High salt content may cause phytotoxicity problems and therefore EC is a good indicator of the suitability and safety of a cast for agricultural practices [31].

Significant difference in nitrogen content between casts and surrounding soil was observed in all the districts of Punjab. In the presence of earthworms nitrogen mineralization is increased, either directly through the release of N by their metabolic products (casts, urine, mucus which contain NH_{4+}, urea, and uric acid) and dead tissues, or indirectly through fragmentation of organic material with other soil organisms [25]. Cortez *et al*., [32] also reported that the presence of earthworms increased the quantity of inorganic N in the soil. Earthworms can impact plant growth by promoting N-availability [33, 34]. The presence of earthworms is also able to increase N mineralization due to active mineralization of carbon (decaying plant root and leaf litter) upon gut passage [35]. Many other studies have reported similar results [36, 21].

The amounts of available phosphorous in earthworm casts were higher by 302% and 509%, respectively, than in soils. Earthworm castings are richer in exchangeable phosphorus [37,38]. Similar observations were made by others [16, 39]. As for the phosphorous status in soil, the increases in available phosphorous were probably caused by modifications in pH (5% improvement) in earthworm casts [41]. As reported by Basker *et al*., 1993 [42] the total potassium and exchangeable potassium contents in earthworm casts were 116 % and 165% greater than the surrounding soil. They further stated that earthworm activity increased amounts of exchangeable K, and concluded that the increase in exchangeable K in cast must be due to the displacement of K+ from the wedge sites of clay minerals by $NH4^+$ ions produced by enhanced mineralisation of organic N.

In cultivated fields, earthworm population play a significant role in soil organic matter (SOM) dynamics through regulation of processes like mineralization and hummification. [15]. The efficiency of earthworms indicates increased transfer of the organic C and N into soil aggregates to facilitate stabilization of SOM and its accumulation in agricultural systems [43]. In present findings, organic carbon was significantly higher in earthworm casts than in surrounding soil, which has also been reported by others in temperate [44,16] and tropical regions [45]. Feeding behaviour of the earthworms which consumed fresh organic fragments from the soil leads to increase in the organic carbon. Earthworms, they enhance mineralization by fragmenting SOM and by mixing SOM, mineral particles and microorganisms, thus creating new contact surfaces between various microorganisms and the SOM [46]. Since earthworms of different ecological groups prefer different food resources, they are likely to affect nutrient mineralization. Anecic earthworms incorporate litter material into the mineral soil thereby making it available for the soil food web. Endogeic earthworm species, in contrasts, primarily consume soil and associated humified OM in the upper layer of the mineral soil [47]. Lavelle and Spain [39] also reported higher level of organic carbon content in vermicasts as compare to surrounding soil. Coq *et al*., [48] showed that casts of endogeic species *Pontoscolex corethrurus* were slightly enriched in C and showed significantly higher mineralization than the non-ingested soil.

Conclusion

Earthworms are important biological factors in soil ecosystems. The highest number of the earthworms were found in SBS Nagar of Punjab so as the nutrients. Nutrient availability is positively correlated with earthworm abundance. It could be concluded that the abundance of earthworm population in soil is beneficial for maintaining the soil nutrient status for sustainability of agricultural practices in the different regions of Punjab. All the tested nutrients showed significantly higher concentrations in casts as compared to surrounding soil. The estimated nutrient enrichment by earthworms was significant, especially for N, and indicates that the casts are valuable nutrient sources for plants.

References

1. Wardle DA. Communities and ecosystems: Linking the aboveground and belowground components. Princeton University Press, Oxford, UK. 2002, 122-130.

2. Nainawat R, Nagendra B. Density and distribution of earthworms in different localities of Jaipur. Journal of Eco-Physiology. 2001; 4:9-13.
3. Julka JM, Paliwal R. Distribution of earthworms in different agro – climatic region of India. Ramakrishnan PS, Sexena KG, Swift MJ, Roaks, Maikhuri RK (ed) In:*Soil biodiversity, ecological processes and landscape*. Oxford and ABH publications Co. Pvt. Ltd, New Delhi, 2005, 3-13.
4. Jouquet P, Ngo TP, Nguyen Hong H, Henry-des-Tureaux T, Chevallier T, Tran Duc T. Laboratory investigation of organic matter mineralization and nutrient leaching from earthworm casts produced by *Amynthas khami*. Applied Soil and Ecology. 2011; 47:24-30.
5. Singh S, Singh J, Vig AP. Earthworm as ecological engineers to change the physico- chemical properties of soil: Soil vs vermicast. Ecology Engineering. 2016; 90:1-510.
6. Kale RD. Earthworms and soil. Proceedings of National Academy of Science India. 1997; 67:13-24.
7. Bossuyt H, Six J, Hendrix PF. Interactive effects of functionally different earthworm species on aggregation, incorporation and decomposition of newly added residue carbon. Geoderma. 2006; 130:14-25.
8. Jouquet P, Zangerle A, Rumpel C, Brunet D, Bottinelli N, Tran Duc T. Relevance and limitations of biogenic and physicogenic classification: a comparison of approaches for differentiating the origin of soil aggregates. Europen Journal of Soil Science. 2009; 60:1117-1125.
9. Barrios E. Soil biota, ecosystem services and land productivity. Ecological Economics. 2007; 64:269-285.
10. Tersic T, Gosar M. Comparison of elemental contents in earthworm cast and soil from a mercury-contaminated site, Idrija area, Slovenia. Science Total Environment. 2012; 430:28-33.
11. Suthar S. Vermistabilization of wastewater sludge from milk processing industry. Ecology Engineering. 2012; 47:115-9.
12. Chaudhuri PS, Nath S, Bhattacharjee S, Paliwal R Biomass, density of earthworm under rubber plantation (*Hevea brasilensis*) in Tripura, India. The Bioscan. 2009; 4(3):475-79.
13. Bossuyt H, Six J, Hendrix PF. Protection of soil carbon by microaggregates within earthworm casts. Soil Biology and Biochemistry. 2005; 37:251-258.
14. Jouquet P, Bottinelli N, Podwojewski P, Hallaire V, Tran Duc T. Chemical and physical properties of earthworm casts as compared to bulk soil under a range of different land-use systems in Vietnam. Geoderma. 2008; 146:231-238.
15. Lavelle P, Martin A. Small-scale and large-scale effects of endogeic earthworms on soil sorganic matter dynamics in soils of the humid tropics. Soil Biology and Biochemistry. 1992; 24:1491-98.
16. Scullion J, Neale S, Philipps L. Comparisons of earthworm populations and cast properties in organic arable rotations. Soil Use and Management. 2002; 18:293-300.
17. Bhadauria T, Saxena KG. Role of earthworms in soil fertility maintenance through the production of biogenic structures. Applied Environment and Soil Science. 2010. Article ID 816073: 1-7.
18. Brown GG, Pashanasi B, Villenave C, Patron JC. Effects of earthworm on plant production. In: *Earthworms Management in Tropical Agroecosystem, eds* P. Lavelle, L. Brussaard and P. Hendrix. CAB International Publishing, 1999, 87-144.
19. Haynes RJ, Fraser PM, Piercy JE, Tregurtha RJ. Casts of *Aporrectodea caliginosa* (Savigny) and *Lumbricus rubellus* (Hoffmeister) differ in microbial activity, nutrient availability and aggregate stability. Pedobiologia. 2003; 47:882-887.
20. Barois I, Villemin G, Lavelle P, Toutain F. Transformation of the soil structure through Pontoscolex corerhrus (oligochaeta) intestinal tract. Geoderma. 1993; 56:57-66.
21. Singh S, Singh J, Vig AP. Earthworm as ecological engineers to change the physico-chemical properties of soil: Soil vs vermicast. Ecological Engineering. 2016; 90:1-5.
22. Mohan VC, Watts P, Kaur A. Diversity and Distribution of Earthworms Species in Guru Nanak Dev University Campus, Amritsar, Punjab, India. Research Journal of Agriculture and Forestry Science. 2013; 1:35-40.
23. Mariappan V, Karthikairaj K, Isaiarasu L. Relationship between earthworm abundance and soil quality of different cultivated lands in rajapalayam, tamilnadu. Journal of World App Science. 2013; 27:1278-1281.
24. Wallwork JA. Earthworm Biology. Edward Arnold, London, England, 1983.
25. Lee KE. Earthworms: their Ecology and Relationships with Soil and Land Use. Academic Press, Sydney, 1985.
26. Kaviraj S, Sharma S. Municipal solid waste management through Vermicomposting employing exotic and local species of earthworms. Bioresource Technology. 2003; 90:169-73.
27. Elvira C, Dominguez JN, Mato S. The growth and reproduction of Lumbricus rubellus and Dendrobaena rubida in cow manure mixed cultures with *Eisenia Andrei*. Applied Soil and Ecology. 1998; 5:97-103.
28. Brady NC. The nature and properties of soils. Collier McMillan Press, London. 1984, 114-1136.
29. Teng SK, Abd Aziz N, Mustafa M, Abd Aziz S, Yan YW. Evaluation on physical, chemical and biological properties of casts of geophagous earthworm, *Metaphire tschiliensis tschiliensis.* Scientific Research and Essays. 2012; 7:1169-1174.
30. Singh A, Singh RV, Saxena AK, Shivay YS, Nain L. Comparative studies on composting efficiency of *Eisenia foetida* (savigny) and *Perionyx excavatus* (perrier). Journal of Experimental Biology and Agricultural Sciences. 2014; 2:52-64.
31. Villar MC, Beloso MC, Acea MJ, Cabaneiro A, Gonazalez P, Diaz R, Carballas T. Physical and chemical characterization of four composted urban refuses. Bioresource Technology. 1993; 45:105-13.
32. Cortez J, Billes G, Bouche MB. Effect of climate, soil type and earthworm activity on nitrogen transfer from a nitrogen-15-labelled decomposing material under field conditions. Biology and Fertility of Soils, 2000; 30:318-327.
33. Li X, Fisk MC, Fahey TJ, Bohlen PJ. Influence of earthworm invasion on soil microbial biomass activity in a northern hardwood forest. Soil Biology and Biochemistry. 2002; 34:1929-37.
34. Ortiz-Ceballos AI, Pena-Cabriales JJ, Fragoso C, Brown GG. Mycorrhizal colonization and nitrogen uptake by

maize: combined effect of tropical earthworms and velvetbean mulch. Biology and Fertiility of Soils. 2007; 44:181-186.
35. Edwards CA, Bohlen PJ. Earthworm ecology and biology. London: Chapman & Hall, 1996.
36. Araujo Y, Luizao FJ, Barros E. Effect of earthworm addition on soil nitrogen availability, microbial biomass and litter decomposition in mesocosms. Biology and Fertility of Soils. 2004; 39:146-152.
37. Sharpley AN, Syers JK. Potential role of earthworm casts for the phosphorus enrichment of run-off waters. Soil Biology and Biochemistry. 1976; 8:341-346.
38. Mansell GP, Syers JK, Greog PEH. Plant availability of phosphorus in dead herbage ingested by surface casting earthworms. Soil Biology and Biochemistry. 1981; 13:163-67.
39. Lavelle P, Spain AV. *Soil Ecology* Kluwer Academic Publishers, Dordrecht/ Boston/ London, 2001.
40. Kuczak CN, Fernande ECM, Lehmann J, Rondon MA, Luizao FJ. Inorganic and organic phosphorus pools in earthworm casts (Glossoscolecidae) and a Brazilian rainforest Oxisol. Soil Biology and Biochemistry. 2006; 38:553-60.
41. Sabrina DT, Hanafi MM, Nor Azwady AA, Mahmud TMM. Earthworm Populations and Cast Properties in the Soils of Oil Palm Plantations. Malaysian Journal of Soil Science. 2009; 13:29.
42. Basker A, Kirkman JH, Macgregor AN. Changes in potassium availability and other soil properties due to soil ingestion by earthworms. Biology and Fertility of Soils. 1993; 17:154-158.
43. Fonte SJ, Kong AYY, Kessel CV, Handrix PF, Six J. Influence of earthworm activity on aggregate-associated carbon and nitrogen dynamics differs with agroecosystem management. Soil Biology and Biochemistry. 2007; 39:1014-22.
44. Zhang H, Schrader S. Earthworm effects on selected physical and chemical properties of soil aggregates. Biology and Fertility of Soils. 1993; 15:229-34.
45. Asawalam DO. Influence of cropping intensity on the production and properties of earthworm casts in a *Leucaena* alley cropping system. Biology and Fertility of Soils. 2006; 42:506-512.
46. Parmelee RW, Bohlen PJ, Blair JM. Earthworms and nutrient cycling processes: integrating across the ecological hierarchy. In: Earthworm ecology, eds. C. Edwards. Boca Raton, FL, USA: CRC Press, 1998, 179-211.
47. Bossuyt H, Six J, Hendrix PF. Interactive effects of functionally different earthworm species on aggregation and incorporation and decomposition of newly added residue carbon. Geoderma 2006; 130:14-25.
48. Coq SB, Barthes G, Oliver R, Rabary B, Blanchart E. Earthworm activity affects soil aggregation and organic matter dynamics according to the quality and localization of crop residues-an experimental study (Madagascar). Soil Biol Biochem. 2007; 39:2119-28.