Tropical Natural History 10(2): 171-179, October 2010

Density, Biomass and Species Richness of Earthworms in Agroecosystems of Garhwal Himalaya, India

NAMITA JOSHI[1*], MADHURI DABRAL[1] AND RAKESH K. MAIKHURI[2]

[1]*Department of Environmental Science, Kanya Gurukul Mahavidyalaya, Gurukul Kangri Vishwavidyalaya, Haridwar- 249407, Uttarakhand, INDIA*
[2]*G.B. Pant Institute of Himalayan Environment and Development, P.B. – 92, Garhwal Unit, Srinagar (Garhwal) 246174, INDIA*
* Corresponding author. E-mail: drnamitaenv@gmail.com
Received: 5 March 2010; Accepted: 26 June 2010

ABSTRACT.– **Earthworm population dynamics were studied at Narayankoti (29°30'3" N and 79°77'02" E) in Garhwal region of western central Himalaya, to evaluate the impact of ecosystem type, quality of organic inputs and land management practices on earthworm population. Earthworm populations were studied in the three agroecosystem types *viz:* agroforestry, intensive and traditional agroecosystems, under different cropping patterns at monthly intervals over a period of two years. A total of eight species belonging to five families was found in the agroecosystems: Moniligastridae (*Drawida nepalensis*), Octochaetidae (*Lennogaster pusillus*), Ocnerodrilidae (*Thatonia exilis* and *Ocnerodrilus occidentalis*), Acanthodrilidae (*Plutellus sadhupulensis* and *Plutellus* sp.) and Megascolecidae (*Metaphire houlleti* and *Perionyx excavatus*). *Drawida nepalensis* had the widest distribution while *O. occidentalis* was found exclusively in agroforestry. *Plutellus sadhupulensis* was absent under agroforestry but was common to intensive and traditional agroecosystems. *Perionyx excavatus* was confined to Intensive only whereas, *Plutellus* sp., *T. exilis*, *L. pusillus* and *M. houlleti* were the species found only in traditional agroecosystems. Density of earthworms and number of species was higher under traditional agroecosystems, may be due to higher moisture content, absence of chemical fertilizer and low perturbations. Biomass of earthworms was significantly higher in intensive and lowest in traditional agroecosystems. Density of earthworm species was higher during summer crops compared to winter crops. This difference may be related to higher moisture, temperature and organic matter content during summer. Earthworm density showed positive correlation with moisture, temperature and organic matter. Earthworm densities were found very low during the fallow phase in all agroecosystems which could be due to absence of plant cover and reduced soil moisture.**

KEY WORDS: **Agroecosystem, Moniligastridae, Acanthodrilidae, Octochaetidae, Megascolicidae**

INTRODUCTION

Ecosystem functions could be defined as" the minimum set of processes that ensures the biological productivity, organizational integrity and perpetuation of the ecosystem" (Swift et al., 2004). The importance of biodiversity in the functioning of agroecosystems is a major question for ecologists. The problem is to use an inventory of the species present that define the biodiversity to understand or predict the capability of a system to fulfill its functions, its resistance to environmental stress and its resilience to recover the previous level of functioning after environmental stress.

Information and analytical studies on the changes on earthworm population brought about by cultivated soils and during crop rotation are limited and scattered (Edwards 1983; Lavelle et al., 1992). Annual crops are reported to be relatively unfavorable systems for soil macro fauna and in general have low earthworm biomass (Lee 1985; Joshi et al., 2009). Further, cultivation

TABLE 1. Values of species density (ind./m^2) total density, total biomass (g/m^2) and species richness in three different agroecosystems.

Species	Agroforestry	Intensive	Traditional
D. nepalensis	174±25.2 115.7±20.8	267±30.2 177.5±28.9	75±14.3 49.8±9.5
O. occidentalis	31±5.2 0.78±0.012		
P. sadhupulensis		25±4.53 1.76±0.15	25±4.53 1.76±0.031
P. excavates		61±12.3 59.78±9.0	
Megascolecid sp.		10±2.9 3.6±1.1	
Plutellus sp.			25±4.53 0.36±0.002
T. exilis			1114±298.6 28.7±4.67
L. pusillus			16±3.12 1.28±0.082
M. houlleti			9±2.9 8.7±2.7
Total density	**205±30.4**	**363±49.93**	**1264±323.18**
Total biomass	**116.48±20.8***	**242.64±39.15***	**90.6±16.9***
Species richness /1000 individuals	**65.52***	**63.07***	**44.19***

{*indicates significance at p<0.05}

techniques during agricultural practices are known to adversely affect earthworm population (Fraser, 1994; Springett et al., 1992).

This study was carried out in the Narayankoti landscape in the Garhwal region of Western Central Himalayas, which includes both natural and human managed ecosystems. This landscape has a variety of management practices determining agro ecosystem function. This study is an attempt to evaluate the population dynamics of earthworm under different landuse in rainfed upland agriculture and asses their diversity in the soil. Therefore, this study makes a comparison between earthworm populations under three agroecosystem viz. Traditional (using FYM and rainfed irrigation), Intensive (using FYM + chemical fertilizer + rainfed irrigation) and Agroforestry.

MATERIALS AND METHODS

The village Narayankoti is located in the Garhwal region of western central Himalaya, which is situated between 29^o 30’3” N and 79^o 77’02” E. The three agroecosystem that were selected for the study were categorized based on the use of inorganic fertilizer and farmyard manure were the traditional, intensive, agroforestry. The cropping pattern follows a complex rotational practice of crops spread over a two year period. During the winter season, a field is either cropped with wheat (*Triticum aestivum*) or fallowed. Summer season crops may exist as a monoculture of upland rice (*Oryiza sativa*) or finger millet (*Elusine coracana*).

Earthworms were collected from three different sites by digging five (25x25x40) cms monoliths at regular intervals of 30

TABLE 2. Soil characteristics of different agro ecosystems under different cropping period (mean of 120 observation ± SE). ([1] indicate significantly (P<0.01) different within cropping pattern between agroecosystems; [2] indicate significantly (P<0.05) different between cropping pattern under agroecosystems).

Site characteristics		Sand%	Silt %	Clay%	Temperature °C	Moisture %	pH	Organic matter %	Nitrogen %
AF	Fallow	14±1.6	51±5.8	35±2.7	15.75 ±2.6[1]	13±2.2[1]	5.3±0.2[1]	1.93±0.5[1]	0.26±0.02[2]
	Rice				27.25 ±4.2[1]	17±2.6[1]	5.6±0.4[1]	1.74±0.4[1]	0.35±0.04[2]
	Wheat				16.0 ±1.8[1]	16±2.5[1]	5.7±0.3[1]	1.87±0.6[1]	0.28±0.03[2]
	Elusine				24.16 ±3.2[1]	16±2.8[1]	5.6±0.4[1]	3.27±0.5[1]	0.35±0.05[2]
INT	Fallow	27±2.6	45±3.4	28±2.4	20.5 ±3.5[1]	11±2.2[1]	5.3±0.2[1]	1.62±0.7[1]	0.28±0.03[2]
	Rice				29.08 ±4.8[1]	19±2.8[1]	5.4±0.2[1]	1.63±0.4[1]	0.32±0.03[2]
	Wheat				18.0 ±2.9[1]	13±2.4[1]	5.6±0.3[1]	1.84±0.4[1]	0.30±0.02[2]
	Elusine				24.8 ±3.4[1]	16±2.4[1]	5.6±0.4[1]	2.70±0.5[1]	0.31±0.03[2]
TD	Fallow	20±2.8	48±4.2	32±2.3	20.0 ±3.7[1]	18±2.7[1]	5.3±0.2[1]	1.81±0.7[1]	0.30±0.01[2]
	Rice				27.75 ±4.6[1]	21±3.3[1]	5.8±0.7[1]	1.67±0.8[1]	0.27±0.02[2]
	Wheat				16.83 ±1.9[1]	17±2.5[1]	5.9±0.9[1]	1.27±0.6[1]	0.31±0.03[2]
	Elusine				23.63 ±3.8[1]	22±3.6[1]	5.8±0.8[1]	2.20±0.5[1]	0.29±0.02[2]

days for 24 months and hand sorting the worms following Anderson and Ingram, 1993 and were preserved in 4% formalin for identification. Density of earthworms was calculated as the number of individuals present per square meter. Biomass was determined by weighing preserved earthworms after having wiped specimens dry on a filter paper.

Random soil samples were collected from each experiment site and standard methods were followed for subsequent analysis. Soil temperature was recorded every month at 0-10 cm depth using soil thermometer. Moisture was determined monthly at 0-10, 10-20, 20-30 and 30-40 cm depth and was expressed as a percentage of the weight of the soil sample after oven drying at 105 °C. Soil pH was measured in 1: 2.5 soil / water solution. Organic matter was determined using complete oxidation method (Nelson and Sommers 1975). Soil nitrogen was analyzed by the microkjeldahl method (Allen et al., 1974). The correlation between soil parameters and earthworm species was calculated as a simple correlation coefficient (r). Variation in density and biomass of earthworm species and soil characteristics across different sampling sites was tested using two ways ANOVA.

RESULTS AND DISCUSSION

Community structure and spatial variation

A total of nine species belonging to five families were found in the agroecosystems: Moniligastridae (*Drawida nepalensis*), Octochaetidae (*Lennogaster pusillus*), Ocnerodrilidae (*Thatonia exilis* and *Ocnerodrilus occidentalis*), Acanthodrilidae (*Plutellus sadhupulensis* and *Plutellus* sp.), Megascolecidae (*Metaphire houlleti* and *Perionyx excavatus*), and Megascolecidae (*Drawida nepalensis*) was present at all sites while *O. occidentalis* was found exclusively in AF. *Plutellus sadhupulensis* was absent under AF but was common to INT and TD. *Perionyx excavatus* was confined to INT only while *Plutellus* sp., *T. exilis*, *L. pusillus* and *M. houlleti* were the species found only in TD. The total density of earthworms (1264±107.2 m^{-2}) was highest under TD and lowest (205±17.7 m^{-2}) under AF. In AF where only two species were sampled (*D. nepalensis* and *O. occidentalis*), density of

TABLE 3. Earthworm population (individuals m^{-2}) and biomass (gm^{-2}, value in parenthesis) under different cropping period in different agroecosystems.

Site	Sampling period	*O. occidentalis*	*D. nepalensis*	*P. sadhupulensis*	*P. excavatus*	Megascolicid sp.	*Plutellus* sp.	*T. exilis*	*L. pusillus*	*M. houlleti*	Juveniles
AF	Fallow	-	9±1.9	-	-	-	-	-	-	-	3±0.90
			(6±1.7)								(0.024±0.001)
	Rice	6±1.8	51±8.4	-	-	-	-	-	-	-	124±11.6
		(0.14±0.05)	(33.9±4.6)								(1±0.01)
	Wheat	19±2.8	3±0.8	-	-	-	-	-	-	-	3±0.8
		(0.5±0.03)	(2±0.9)								(0.024±0.001)
	Elusine	6±1.6	111±22.2	-	-	-	-	-	-	-	3±0.9
		(0.14±0.04)	(73.8±13.6)								(0.024±0.001)
INT	Fallow	-	45±6.7	6±1.8	-	-	-	-	-	-	-
			(30±3.5)	(0.42±0.03)							
	Rice	-	134±41.2	6±1.9	42±6.6	10±2.1	-	-	-	-	26±3.2
			(89.1±15.2)	(0.42±0.04)	(41.16±6.5)	(3.6±1.1)					(0.28±0.02)
	Wheat	-	6±1.5	-	-	-	-	-	-	-	10±1.7
			(4±1.2)								(0.11±0.01)
	Elusine	-	82±14.6	13±2.3	19±2.5	-	-	-	-	-	-
			(54.4±9.0)	(0.92±0.08)	(18.62±2.5)						
TD	Fallow	-	9±1.8	-	-	-	3±1.0	32±3.8	-	-	19±2.5
			(6±1.9)				(0.04±0.001)	(0.83±0.04)			(0.19±0.01)
	Rice	-	25±3.5	3±0.9	-	-	13±2.4	816±80.2	3±0.8	-	19±2.3
			(16.6±3.2)	(0.21±0.01)			(0.19±0.02)	(21.2±3.2)	(0.24±0.002)		(0.19±0.02)
	Wheat	-	12±2.1	-	-	-	9±1.6	22±3.1	-	3±0.9	16±1.4
			(8±1.5)				(0.13±0.01)	(0.57±0.03)		(29±1.0)	(0.16±0.01)
	Elusine	-	29±3.2	22±3.0	-	-	-	244±20.6	13±2.5	6±1.9	10±1.3
			(19.2±2.9)	(1.5±0.5)				(6.1±1.4)	(1.04±0.08)	(5.8±1.7)	(0.10±0.01)

earthworm was higher (115±20.8 m^{-2}) under Elusine and lower (9±2.9 m^{-2}) under fallow phase of cropping pattern (Table 1). Among the four species found in INT, density of earthworms was higher (192±51.8 m^{-2}) during rice crop and lower (6±1.5 m^{-2}) during wheat crop (Table 3). Only *D. nepalensis* was the species found during all the cropping phase and all the four species in INT were present during rice crop. *D. nepalensis* had a significantly (F=4.63, P< 0.05) higher density among the species found during every cropping period. In traditional agroecosystem the total density of earthworms was highest (860±87.8 m^{-2}) in rice crop and lowest (44±3.8 m^{-2}) during fallow phase. Rice and Elusine crop had maximum while, fallow and wheat had minimum number of species. No, significant change was found in the density of earthworms under varied cropping pattern. Juvenile density was higher (130±12.6 m^{-2}) in AF and lower (36±1.6 m^{-2}) in INT agroecosystem. Rice crop had the highest density of juveniles among all the three agroecosystem. While in terms of biomass, earthworm biomass was maximum (73.94± 13.64 gm^{-2}) during Elusine and minimum (2.5±0.93 gm^{-2}) during wheat crop in AF. In INT biomass of earthworms was higher (134.28±22.84 gm^{-2}) during rice crop and lower (4±0.9 gm^{-2}) during wheat crop. *D. nepalensis* had a significantly (F=6.36, P<0.05) higher biomass under AF and INT agroecosystems and in the different cropping pattern. In TD, biomass of earthworms was again highest (38.44±4.66 gm^{-2}) during rice crop and lowest (6.87± 0.95 gm^{-2}) during fallow phase. Under fallow, wheat and Elusine, *D. nepalensis* and under rice *T. exilis* had significantly (F=5.25, P<0.01) higher biomass in TD. In general, density of each earthworm species was higher under summer crops (Elusine and rice) compared to winter crop (wheat) in all agroecosystems with the exception of *O. occidentalis* which had highest density in winter crop (wheat) and was only present in AF, while absent in TD and INT agroecosystem.

Site characteristics

Soil temperature between different agroecosystems types differed with the lowest values (15.75±2.6 ^{o}C) observed for AF in fallow phase and the highest (29.08± 4.8 ^{o}C) for INT during rice crop (Table 2). Soil moisture was found higher during the summer crops (rice and Elusine) compared to the winter crop (wheat). Soil moisture was highest (22±3.6 %) in TD during *E. coracana* than that in AF and INT (Table 2).

Physicochemical properties of the soil differed between agroecosystems (Table 2). Sand content (27±2.6 %) was highest in INT while silt (51±5.8 %) and clay (35±2.7%) content was highest in AF. Soil pH was highest (5.9±0.9) in TD during wheat crop while it was found lowest among all the sites during fallow phase. Furthermore, concentration on organic matter was highest (3.27±0.5 %) during Elusine crop in AF while lowest (1.27±0.6 %) value was noted during wheat crop in TD. Nitrogen percent was noted maximum (0.35±0.04 %) during summer crops (rice and Elusine) and minimum (0.26±0.02 %) during fallow phase in AF. The impacts of management practices on earthworm population depends upon the landuse histories e.g. conversion of nutrient poor savanna to native pastures follows an increase but native forests to pastures a decrease in earthworm diversity (Lavelle et al., 1994; Brown et al., 2004). The landuse change – earthworm population, abundance and diversity depends upon the nature and magnitude of changes in environment coupled with the landuse change. Thus, agriculture may have a positive effect on earthworms if it improves food supply as a result of recycling of nutritious crop residues, organic manure is added to the soil and loosening of soil occurs to an extent that facilitates burrowing by earthworms (Lagerlof et al., 2002). Changes in landuse pattern and vegetation structure results in significant differences in micro habitat conditions such as physicochemical properties and soil temperature, which in turn alter the earthworm population structure (Bhadauria and Ramakrishnan, 1991; Hendrix et al., 1992; Blanchart and Julka, 1997; Jordan et al., 1997; Bhadauria et al., 2000). Major determinants of earthworm community structure in an agroecosystems are the quantity and quality of organic matter added (Lavelle et al., 1994), soil type (Fraser, 1994), and the influence of the disturbances (Werner and Dindal, 1990) with better adaptation and tolerance to various disturbances during crop rotation, *D. nepalensis* had a wider distribution during crop rotation at all the sites, with higher densities. *Metaphire houlleti* occurred in TD agroecosystem showed a significant positive correlation with organic matter only. *Lennogaster pusillus* and *T. exilis* were confined to TD agroecosystems while *P. excavatus* to intensive agroecosystem and *O. occidentalis* to AF. *Plutellus sadhupulensis* was present in INT and TD. Number of species was recorded maximum in TD system under

TABLE 4. Correlation coefficient (r) for soil parameters and earthworm density.

Species	Moisture %	Temperature °C	pH	Organic matter	Sample Size(n)
D. nepalensis	0.727**	0.456*	0.430*	-0.237	21
L. pusillus	-0.949	-0.374	0.476	0.917	3
Megacsolicid species	-	-	-	-	1
M. houlleti	-1	-1	-1	-1	2
O. occidentalis	-0.153	-0.365	-0.365	0.563	3
P. excavatus	-0.513	-0.829	0.948	0.554	3
Plutellus sp.	0.095	0.813	0.418	-0.550	4
P. sadhupulensis	-0.418	-0.174	-0.451	0.074	7
T. exilis	0.444	0.430	-0.583*	0.115	11
Total density	0.537**	0.490**	-0.184	0.423*	23
Biomass	0.612**	0.578**	-0.350*	0.366*	23
Species richness	-0.464*	-0.409*	0.287	0.650**	23

Significant at $P<0.01$**, $P<0.05$*

different agroecosystems; this may be due to preference of earthworm species for higher soil moisture, pH and mild temperature conditions combined with their sensitivity to perturbations. *Thatonia exilis* which was confined to TD agroecosystem with the highest density may be due to higher moisture content, absence of chemical fertilizer and low input perturbation.

Addition of organic manure twice, at the beginning of the cropping period both in the rice crop and in the *E. coracana* crop (June to July) was correlated with an increase of earthworm population. Such an increase in the species number subsequent to the addition of organic manure during crop rotation has also been reported by Edwards and Lofty (1972). Removal of most of the crop residues from the fields after the harvesting of the first crop mixture, ploughing, harrowing and cult discing or preparing the soil surface for planting of crops, along with low soil moisture and temperature, resulted in the decline of all the earthworm species in the wheat crop mixture (November to April), such observations was also be noted by Lofs Holmin (1983). The higher population of *O. occidentalis* during the winter season could be related to its tolerance to lower soil moisture and temperature and also to the patchy distribution of these species on the margins of the terraces. Increase in the population of different earthworm species again during *E. coracana* was probably related to the improved nutrients in the soil because of ploughing back of the roots of cereals and crop by products, and through the addition of organic manure to the soil preceding the planting of *E. coracana* (Edwards, 1983; Werner and Dindal, 1990). Earthworm population densities was found very low during the fallow period under agroecosystems and may be due to absence of plant cover, reduced soil moisture (Edwards and Lofty 1972) and also to trampling pressure on the soil as a result of grazing by cattle (Cleuzeau et al., 1992). Seasonal increase in the adult population of all the earthworm species except *O. occidentalis* during the monsoon season at all the sites was more common and was due to favorable soil moisture and temperature conditions (Valle et al., 1997) and improved microbial activity (Fragoso and Lavelle 1992). Earthworm population density at a specific site is the result of the interaction of a number of factors such as soil texture, moisture, pH and organic matter content (Blanchart and Julka, 1997; Lavelle, 1993; Satchell, 1983). Most researchers have found earthworms almost exclusively in the top 50 cm of agricultural soil and most species have been found in the top 20 cm (Clapperton et al., 2001; Valle et al., 1997). The data obtained in the present work fits in this pattern of distribution for the earthworm population as a whole, the study suggests that earthworms move through the profile in accordance with rainfall; migrating towards the top 20cm during humid months and burying themselves deeper during the drier periods. Difference in the vertical distribution of the C:N ratio at 0-10 and 10-20cm the organic matter content seems to be the most important factor in earthworm distribution.

In the present study, numerical abundance and species richness of earthworms under TD agroecosystem type was found higher as compared to that reported by Bhadauria and Ramakrishnan (1991) and Bhadauria et al. (1997, 2000) for north eastern India and Kumaon Himalayas.

Correlation between earthworm density and soil parameters

A significant positive correlation was noted between the size of earthworm population and soil parameters such as moisture, temperature, pH and organic matter (Table 4). *D. nepalensis* showed significantly positive correlation with moisture (r=0.955, P<0.01), organic matter (0.854, P<0.05) and temperature (r=0.993, P<0.01). *Lennogaster pusillus* showed significant positive correlation with moisture (r=0.840, P<0.01) and organic matter (r=0.818, P<0.05). Megascolecid species showed significant positive correlation with moisture and temperature (r=0.809, P<0.05 and r=0.818, P<0.05). *Metaphire houlleti* showed significant positive correlation with organic matter (r=0.944, P<0.01). *Ocnerodrilus occidenttalis* showed significant positive correlation with pH (r=0.828, P<0.05) only. *Plutellus excavatus* showed significant positive correlation with moisture (r=0.965, P<0.01) and temperature (r=0. 974, P<0.01). *Plutellus* sp. showed significant positive correlation with moisture (r=0.996, P<0.01), temperature (r=0.855, P<0.05), organic matter (r=0.826, P<0.05) and significantly negative correlation with pH (r=-0.866, P<0.05). *Plutellus sadhupulensis* showed significantly positive correlation with temperature and organic matter (r=0.825, P<0.05 and r=0.963, P<0.01). While *T. exilis* showed a highly significant positive correlation with temperature (r=0.921, P<0.01).

ACKNOWLEDGEMENTS

We thank Dr. J.M. Julka, (Scientist) ZSI, Solan, for identifying the earthworms and the anonymous referees for very useful comments and suggestions.

LITERATURE CITED

Allen, S.E., Parkinson, J.P. and Quarmby, C. 1974. Chemical analysis of ecological materials. Blackwell Scientific Publications, Oxford.

Anderson, J.M. and Ingram, J.S.I. 1993. Tropical Soil Biology and Fertility: A Handbook of methods. CAB International, Wallingford.

Bhadauria, T. and Ramakrishnan, P.S. 1991. Population dynamics of earthworms and their activity in forest ecosystem of north east India. Journal of Tropical Ecology. 7: 305-318.

Bhadauria, T., Ramakrishnan, P.S. and Srivastava, K.N. 1997. Population dynamics of earthworms during crop rotation under rainfed agriculture in central Himalayas, India. Applied. Soil Ecology. 6: 205-215.

Bhadauria, T., Ramakrishnan, P.S. and Srivastava, K.N. 2000. Diversity and distribution of endemic and exotic earthworms in natural and regenerating ecosystems in the central Himalayas, India. Soil Biology and Biochemistry. 32: 2045- 2054.

Blanchart, E. and Julka, J.M. 1997. Influence of forest disturbance on earthworm communities in Western Ghat, South India. Soil Biology and Biochemistry. 29: 303-306.

Brown, G.G., Edwards, C.A. and Brussard, L. 2004. How earthworms affect plant growth burrowing into mechanisms. In: Earthworm Ecology. Edwards, C.A. (ed.). CRC Press, LLC Boca Raton. FL. pp 13-15.

Clpperton, M.J., Lee, N.O., Binet, F. and Conner, R.L 2001. Earthworms indirectly reduced the effects of take all (*Gaeumannomyces graminis*) on soft white spring wheat (*Triticum aestivum* Fielder). Soil Biology and Biochemistry. 33: 1531-1538.

Cluzeau, D., Fayolle, L. and Hubert, M. 1992. The adaption value of reproductive strategy and mode in three epigeons species. Soil Biology an Biochemistry. 24: 1309-1315.

Dash, A.K. and Patra, U.C. 1977. Density, biomass and energy budget of a tropical earthworm population from a grassland site in Orissa, India. Revue D'Ecologie et de Biologie du Soil. 14: 461-471.

Didden, W.A.M. 2001. Earthworm communities in grasslands and horticultural soils. Biology and Fertility of Soils. 33: 111-117.

Dotson, D.B. and Kalisz, P.J. 1989. Characteristics and ecological relationship of earthworm assemblages in undisturbed forest soils in the southern Applachians of Kentucky U.S.A. Pedobiologia. 33: 211-230.

Edwards, C.A. 1983. Earthworm ecology in cultivated soil. In: Satchell, J.E. (ed.). Earthworm Ecology From Darwin to Vermiculture. Chapman and Hall, London, pp. 123-138.

Edwards, C.A. and Lofty, J.R. 1972. Biology of Earthworms. Chapman and Hall, London.

Edwards, C.A., and Bohlen, P.J. 1996. Biology and Ecoloogy of Earthworms. Chapman and Hall, London.

Fragoso, C. and Lavelle, P. 1992. Earthworm communities in tropical rain forests. Soil Biology and Biochemistry. 24: 1397-1409.

Fragoso, C., Barois, I., Gonzalez, C., Arteaga, C. and Patron, J.C. 1993. Relationship between earth-worms and soil organic matter levels in natural and managed ecosystem in the Mexican Tropics. In: Mulongoy, K. and Merckx, R. (eds). Soil Organic Matter Dynamics and Sustainability of Tropical Agriculture. Wiley-Sayce Co-Publication, UK, pp. 231-239.

Fraser, P.M. 1994. The impact of soil and crop management practices on soil macrofauna. In: Pankhurst, C.E., Doube, B.M., Gupta, V.V.S.R. and Grace, P.R. (eds). Soil Biota Management in Sustainable Farming Systems. Transactions of 15th World Congress of Soil Science. Acapulco, Mexico, Vol. 4a, pp. 55-56.

Hendrix, P.F., Muller, B.R., Bruce, R.R., Langdale, G.W. and Parmelee, R.W. 1992. Abundance and Distribution of earthworms in relation to landscape factors on the Georgia Piedmont, U. S. A. Soil Biology and Biochemistry. 24: 1357-1361.

Jordan, D., Stecker, J.A., Cacnio-Hubbard, V.N., Li. F., Gantzer, C.J. and Brown, J.R. 1997. Earthworm activity in no-tillage and conventional tillage systems in Missouri soils: a preliminary study. Soil Biology and Biochemistry. 29: 489-491.

Joshi, N. and Aga, S. 2009. Diversity and distribution of earthworms in a subtropical forest ecosystem in Uttarakhand, India. The Natural History Journal of Chulalongkorn University. 9: 21-25.

Kaushal, B.R., Kalia, S. and Bisht, P.S. 1995. Growth and cocoon production by the earthworm *Drawida nepalensis* (Oligochaeta: Moniligastridae) in oak and pine litter. Pedobiologia 39: 417-422.

Lagerlof, J., Goffre, B. and Vincent, C. 2002. The importance of field boundaries for earthworms (Lumbricidae) in the Swedish agricultural landscape. Agriculture, Ecosystem and Environment. 89: 91-103.

Lavelle, P. 1993. The structure of earthworm communities. In: Satchell, J.E. (ed.). Earthworm Ecology from Darwin to Vermiculture. Chapman and Hall, London, pp. 449-446.

Lavelle, P., Gilot, C., Fragoso, C. and Pashanasi, B. 1994. Soil fauna and sustainable landuse in the humid tropics, In: Greenland, D. J. and Szabolcs, J. (eds). Soil Resilience and sustainable landuse. CAB International, Wallingford, pp. 291-308.

Lavelle, P., Spain, A., Blanchart, E., Martin, A. and Martin, S. 1992. Impact of soil fauna on the properties of soil in the humid tropics. In: Sanchez, P.A. and Lal, R. (eds). Myths and science of soils in the tropics. Soil Science Society, America. Special Publication No. 29. Maddison, pp. 157-185.

Lee, K.E. 1985. Earthworms: Their Ecology and Relationship with Soils and landuse. Academic Press, Sydney.

Lofs-Holmin, A. 1983. Earthworm population dynamics in different agricultural rotations. In: Satchell, J.E. (ed.). Earthworm Ecology from Darwin to Vermiculture. Chapman and Hall, London, pp. 627-634.

Nelson, D.W. and Sommers, L.E. 1975. A rapid and accurate method for estimating organic carbon in soil. Proceedings of the Indian Academy of sciences 84: 456-462.

Nemeth, A. and Herrera, R. 1982. Earthworm populations in a Venezuelan tropical rain forest. Pedobiologia. 23: 437-443.

Okalebo, J.R., Gathua, K.W. and Woomer, P.L. 1993. Laboratory methods of Soil and Plant Analysis: A Working Manual. T.S.B.F., UNESCO-ROSTA, Nairobi, Kenya.

Rosswall, T. and Paustian, K. 1984. Cycling of nitrogen in modern agricultural systems. Plant and Soil. 76: 3-21.

Satchell, J.E. 1983. Earthworm ecology in forest soil. In: Satchell, J.E. (ed.). Earthworm Ecology from Darwin to Vermiculture, Chapman and Hall, London, pp. 161-170.

Sinha, B. 2002. Ecological Analysis of A Sacred Landscape in Garhwal Himalaya. Ph.D. Thesis, Jawaharlal Nehru University, New Delhi, India.

Springett, J.A., Gray, R.A.J. and Reid, J.B. 1992. Effects of introducing earthworms into horticultural and previously denuded of earthworms. Soil Biology and Biochemistry. 24: 1615-1622.

Swift, M.J., Heal, O. and Anderson, J.M. 1979. Decomposition in terrestrial ecosystem. Blackwell Scientific Publications, Oxford.

Valle, J.V., Moro, R.P., Gravin, H.M., Trigo, D. and Cosin, D.D.J. 1997. Annual dynamics of the earthworm *Hormogaster elisae* (Oligochaeta: Hormogastridae) in central Spain. Soil Biology and Biochemistry. 29: 309-312.

Watanabe, F.S. and Olson, S.R. 1965. Test of an Ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soils. Proceedings of Soil Science Society of America. 29: 677-678.

Werner, M.R. and Dindal, D.L. 1990. Earthworm community dynamics in conventional and low input agroecosystems. Revue D'Ecologie et de Biologie du Soil. 26: 427-437.