Asian Jr. of Microbiol. Biotech. Env. Sc. Vol. 25, No. (4) : 2023 : 651-657

ISSN-0972-3005

DOI No.: http://doi.org/10.53550/AJMBES.2023.v25i04.008

MONTHLY VARIATION IN THE POPULATION AND BIOMASS OF EARTHWORMS IN RELATION TO ECOLOGICAL FACTORS FROM CROPLAND SITE AT RANCHI, JHARKHAND

MRIDULA KUMARI, ROHIT SRIVASTAVA[2], MANOJ KUMAR[3] AND M.P. SINHA[2]

[1]Y.N. College, Dighwara, Bihar
[2]P.G. Deptt. of Zoology, Ranchi University, Ranchi 834 008, Jharkhand, India
[3]St. Xavier's College, Ranchi, Jharkhand, India

(Received 14 May, 2023; Accepted 4 July, 2023)

Key words: *Population, Cropland, Biomass, Juvenile, Clitellate*

Abstract– Fluctuation of population density of the worms was assessed from a tropical cropland site at Ranchi for twenty months. The density of the worms was maximum in August 2008 and minimum in May 2008 respectively. Of the various factors studied rainfall, relative humidity, soil moisture, organic carbon and nitrogen content of the soil showed a significant positive correlation with the total worm density and biomass. Soil moisture content of the soil was considered to be the most important single factor responsible for the population fluctuation of the earthworms.

INTRODUCTION

Invertebrate biomass is dominated by earthworms in grassland and pasture ecosystem of the world (Dash, 1978). Earthworm ecology and biology have been studied since the contribution of Darwin (1881). The density of worms depends on the type of soil, its physico chemical characteristics and ecological factors mainly soil temperature and soil moisture. Earthworms are often referred to as ecosystem engineers for their ability to maintain the structure of soil and its fertility. It also has a significant role in nutrient dynamics and microbial community (Barlett *et al.,* 2010; Edwards and Bohlen, 1996; Fragoso *et al.,* 1997; Sims and Gerard, 1999; Jones *et al.,* 1994).

89% of the total worm density in India is composed of native species (Julka and Paliwal, 2005). Several research works have been carried out across the globe which investigated the relationship between earthworm activity and its climo edaphic factors, but there is a considerable gap of knowledge exists in the field of earthworm ecology so far functional role of earthworm is concerned particularly in cropland of tropics in general and India in particular. No information is available on this aspect from Indian cropland. Keeping the above in background the present study was carried to study the population dynamics of the worms from a cropland site at Ranchi, Jharkhand.

MATERIALS AND METHODS

The present work was carried out in a tropical cropland site located near Ranchi University campus. Plot of 100 m^2 area was chosen for the field study. The sampling plot was equally divided into 100 subplots, each of 1 m^2 area.

Soil temperature and Soil moisture was measured with the help of soil thermometer (^{0}C) and oven drying method respectively. The Department of Agricultural Physics, Birsa Agricultural University, Kanke provided the data of Air temperature (^{o}C), rainfall (mm) and relative humidity (%) for the study period.

Monolith method was employed for sampling and earthworms were hand sorted once per month as per Dash and Patra (1972) and Ali *et al.,* (1973) during morning hours. On the basis of length and clitellar development earthworms were separated into different size groups, i.e. < 2 cm (juvenile), ≤ 2 cm and < 4 cm (non clitellate, immature) and ≥ 4 cm (clitellate, adult). The population was expressed as number of individuals per square meter.

Five freshly collected worms of each size group were weighed after gut clearance separately to obtain wet weight and were kept in oven at 85 °C for 24 h to obtain dry weight. Gut content clearance of worms was made by keeping the woms in moist filter paper for 24 hrs.

RESULTS

The physico chemical parameters of soil of the study site has been presented in Table 1.

Table 1. Variation in edaphic factors during the study period.

Soil texture	
Sand	44.60 ± 5.2
Silt	30.0 ± 1.7
Clay	25.40 ± 2.1
Soil pH	6.10 ± 0.05
Soil Temperature	24.22°C
Organic carbon content	5.99 ± 0.06mg C g^{-1}
Nitrogen content	0.75 ± 0.01mg N g^{-1}
Phosphorus content	29.65 ± 0.70kg P $hectare^{-1}$
Potassium content	148.56 ± 0.73kg K $hectare^{-1}$
Soil respiration	6.45 ± 0.13 mg CO_2 kg^{-1} hr^{-1}
Soil moisture	16.45%

Population density and dynamics

Three species of earthworms *Ocnerodrilus occidentalis* (Eisen), *Lampito mauritii* (Kinberg) and *Perionyx excavatus* (Perrier) were found in the sampling site. Of the 3 species *Lampito mauritii* was the dominant species having I.V. value of 48.78%. The total population density as well as density of different species at the study site has been presented in Table -2. The total density ranged between 40±15.14 to 750±86.66m^{-2} in May 2008 and September 2008 respectively. The average monthly worm density during the study period was 293.25m^{-2}. Worm density constituted 16.31% of juveniles, 68.12% of immature and 15.07% of adult worms. Correlation coefficient of different climo edaphic parameters with total worm density and biomass has been presented in Table 3.

Table 3. Correlation coefficient of different climo edaphic parameters with total worm density and Biomass.

Parameters	Total Worm Density	Total Worm Biomass
Soil moisture	0.914*	0.911*
Soil temperature	0.074***	-0.036
Relative humidity	0.895*	0.853*
Organic carbon	0.874*	0.903*
Nitrogen	0.864*	0.839*
Rainfall	0.815*	0.709**
Air temperature	-0.329	0.241***

*p<0.001, ** p<0.01, *** NS

Biomass variation

The average monthly worm biomass was 13.01g dry

Table 2. Monthly variation in total density (No./m^2/month±SEM) of different earthworms in cropland

Month	*L. mauritii*	*P. excavatus*	*O.occidentalis*	Total
Jul/07	105±25.41	95±20.54	130±21.98	330±68.85
Aug/07	180±35.65	180±25.47	260±28.98	620±89.95
Sep/07	240±46.21	210±35.98	300±35.45	750±86.66
Oct/07	165±20.14	115±16.89	190±25.87	470±78.95
Nov/07	105±35.85	85±20.85	120±25.67	310±55.21
Dec/07	80±24.11	55±19.05	65±12.65	200±51.98
Jan/08	60±21.36	10±3.01	35±9.75	105±45.65
Feb/08	70±25.15	30±4.69	70±15.66	170±35.78
Mar/08	105±34.25	45±15.25	70±17.87	220±87.71
Apr/08	35±10.30	0	25±12.52	60±21.98
May/08	25±5.05	0	15±2.01	40±15.14
Jun/08	45±9.06	15±4.41	20±11.05	80±27.66
Jul/08	150±18.87	100±25.98	180±29.87	430±87.98
Aug/08	255±31.54	170±41.65	295±35.84	720±95.47
Sep/08	205±29.14	105±34.54	190±24.41	500±75.87
Oct/08	155±27.25	65±22.54	125±35.69	345±68.45
Nov/08	80±29.25	45±15.32	55±8.45	180±58.98
Dec/08	60±21.41	30±4.98	40±5.36	130±22.65
Jan/09	35±10.11	20±4.61	35±7.56	90±29.87
Feb/09	75±15.42	25±11.20	55±22.12	155±33.68

wt. m^{-2}. The total biomass during study period ranged between 2.17 ± 0.65g dry wt. m^{-2} to 29.06 ± 8.81g dry wt. m^{-2} in May 2008 and September 2007 (Table 4). The total worm biomass constitute by 1.87% of juvenile, 81.48% of immature and 16.65% of mature worms during the study period.

DISCUSSION

Two species of earthworm (*Lampito mauritii* and *Ocnerodrilus occidentalis)* have been reported in a grassland soil of southern Orissa, India (Dash and Patra, 1977). *Lampito mauritii* was the dominant species having I. V. value 89%. Senapati and Dash (1981) reported occurrence of 5 species (*O. surensis, D. calebi, L. mauritii, D. willsi* and *O. occidentalis*) from a grazed and ungrazed pasture plots of western Orissa, India. *O. surensis* constituted 50% of the earthworm biomass and number. Srivastava *et al.* (2012) reported four species of earthworm (*Ocnerodrilus occidentalis, Glyphidrilus tuberosus, Lampito mauritii* and *Drawida calebi*) from an agroecosystem of Jharkhand among them *Ocnerodrilus occidentalis* was the dominant species having I. V. value greater than 90%. Joshi *et al.* (2010) reported eight earthworm species belonging to five, families from the agro ecosystems of the Garhwal, Himalaya. *Drawida nepalensis* was the dominant species among them.

The present work showed the presence of 3 earthworm species from a cropland site namely *Lampito mauritii, Ocnerodrilus occidentalis* and *Perionyx excavatus.* Of these 3 species *Lampito mauritii* was the most dominant species with I. V. value of 48.78%. In India, *Lampito mauritii* is the most widely distributed earthworm in different agroecosystems (Dash and Patra, 1977; Kale and Krishnamoorthy, 1982; Karmegam and Daniel, 2007; Sathianarayanan and Khan, 2006).

Comparison of density of earthworms in different habitats is important to reach at some general conclusions and to make generalization. Habitat suitability and prevailing climatic conditions of the region is responsible for high and low population density. The abundance of earthworm population usually depends on soil texture, the regional variation in vegetation, nutrient content and the occurrence of dry and wet periods. The distribution of earthworms does not depend solely on single factor but on a number of factors. Effect of various climatic and edaphic factors was responsible for the distribution and abundance of earthworms in soil of an area. Evans and Guild (1947), El Duweini and Ghabbour (1964, 1965), Gerard (1967), Satchell (1955, 1967), Nakamura (1968), Madge (1969), Edwards and Lofty (1972, 1977), Dash *et al.,* (1974), Dash and Patra (1977), Lavelle (1978), Senapati and Dash (1984), Mirshra *et al.,* (1985), Sinha *et al.,* (2003), Lavelle (1978), Karmegam and Daniel (2007) and Srivastava *et al.,*

Table 4. Seasonal dynamics of biomass (g.dry wt./m^2/month ± SEM) of different species in cropland site.

Month	*O. occidentalis*	*P. excavatus*	*L. mauritii*	Total
Jul-07	4.00±1.04	3.72±0.98	4.56±0.65	12.28±6.73
Aug-07	7.55±1.65	6.61±2.05	7.39±0.98	21.55±7.91
Sep-07	8.72±2.01	8.06±2.65	12.28±1.21	29.06±8.81
Oct-07	7.69±1.21	5.47±1.01	9.14±0.65	22.30±6.61
Nov-07	5.16±0.45	4.53±0.95	6.23±0.65	15.92±5.98
Dec-07	2.91±0.41	3.09±0.65	4.81±0.45	10.81±4.65
Jan-08	1.54±0.25	0.56±0.06	3.54±0.79	5.64±4.01
Feb-08	3.17±0.33	1.62±0.45	4.25±0.75	9.04±4.26
Mar-08	3.88±0.31	2.08±0.71	6.45±0.95	11.91±4.03
Apr-08	1.12±0.26	0.00	2.10±0.62	3.22±3.31
May-08	0.67±0.06	0.00	1.50±0.43	2.17±0.65
Jun-08	0.90±0.06	0.82±0.2	2.25±0.82	3.97±1.95
Jul-08	5.55±0.69	4.15±0.65	6.61±1.03	16.31±7.25
Aug-08	9.20±2.15	5.98±1.02	10.87±1.52	26.05±7.95
Sep-08	6.86±0.98	4.36±0.85	11.03±1.98	22.25±6.61
Oct-08	4.81±0.37	3.28±0.63	9.16±0.54	17.25±5.91
Nov-08	2.44±0.61	2.48±0.45	3.65±0.89	9.95±5.01
Dec-08	1.80±0.42	1.68±0.32	2.06±0.42	7.13±2.26
Jan-09	1.51±0.13	1.10±0.16	4.50±0.79	4.67±1.96
Feb-09	3.10±0.12	1.12±0.13	117.41	8.72±1.15

(2012), have stressed the importance of soil moisture and temperature on earthworm activity.

Earthworm activity is restricted to rainy and post rainy season in Indian conditions have been reported by Gates (1961), Dash and Patra (1977), Kale and Krishnamoorthy (1982), Bhaduria and Ramakrishnan (1991) and Tripathi and Bhardwaj (2004). Earthworms are mostly active in the 4-6 months of the rainy season in the humid tropical and subtropical climate of India and monsoon tropical climate of Burma (Gates, 1961). The population of *M. posthuma, L. mauritii* and *D. bolaui* was found to be maximum during the months of July to October in the desert region of Rajasthan (Tripathi and Bhardwaj, 2004). The highest value of earthworm density and biomass appeared at the onset of wet season (October-December) when all the population was active, in the forest and pastures of Colombian Andes (Fragoso *et al.,* 1997). In the present investigation earthworm population was high in rainy season (July to September) and is in conformity with the earlier reports.

Haokip and Singh (2012) reported that rainfall together with relative humidity during rainy season leads to the increase in earthworm population and in the present investigation a positive correlation with relative humidity (r=895; $p<0.001$) is in agreement with above findings.

Srivastava (2002) reported a minimum density of 75 m^2 in June and maximum density of 7600 m^{-2} in August of *Ocnerodrilus occidentalis* in a tropical agroecosystem of Jharkhand. The earthworm population showed significant positive correlation ($r = 0.913$, $p<0.001$) with soil moisture indicating the hydrophilic nature of earthworm. Tondoh and Lavelle (2005) investigated the population dynamics of the exotic earthworm *Hyperiodrilus africanus* in a secondary forest of the Natural reserve of Lampto (Ivory Coast), Africa and reported that three factors rainfall, soil water and seasonality are likely to control population dynamics. The dry season appears to be the most important environmental factor that regulates population abundance when predation, density-dependent regulation and competition phenomena are ignored. Timmerman *et al.* (2006) also reported low earthworm abundance due to low temperature.

The Ranchi district has a tropical climate with a hot dry summer followed by monsoon and winter. Soil moisture showed significant positive correlation ($r=0.914$; $p<0.001$) and air temperature showed non significant correlation ($r=0.074$) with number of earthworms indicating the importance of moisture and temperature for growth and survival of earthworm population. The soil moisture due to rain might be the causative factor for higher population density during the present investigation, through decreasing the limiting impact of temperature due to interaction of factors.

Temperature, moisture and food supply are the major components of the earthworm habitat. Kale (1998) reported that abundance and diversity of earthworm species is affected by carbon and nitrogen content of the soil. Tripathi and Bhardwaj (2004) have reported that organic carbon and nitrogen in significantly correlated with the distribution of the worms. Nurhidayati *et al.,* (2011) reported that increasing the c-organic and nitrogen content by 25% each can increase earthworm's density by 64% and 79% respectively. Haokip and Singh (2012) also reported significant and positive correlation between earthworm population and organic carbon and nitrogen content of the soil. In the present study soil organic carbon and nitrogen content of the soil showed significant positive correlation ($r=0.874$; $p<0.01$, $r=0.864$; $p<0.01$) with number of earthworms indicating the importance of carbon and nitrogen for growth and survival of earthworms population.

Madge (1969) has estimated the density (No m^{-2}) of earthworm in a tropical forest of Nigeria to be 34 whereas the density of earthworms in Ugandan soil was 10-20 (Block and Banage, 1968). The density of earthworm in a cropland site of India was 64-800 m^{-2} (Dash and Patra, 1977). Sinha and Srivastava (2001) reported that the population density (No m^{-2}) of *Perionyx sansibaricus* earthworm was 375 to 10050 in a garbage site of Jharkhand near Ranchi. Bisht *et al.,* (2003) reported earthworm density (No m^{-2}) to be 6.2 – 13.9 in the maize crop, 5.4 – 19.0 in the paddy and pulses crop and 0 – 9.8 in wheat and mustard crop. Joshi *et al.,* (2010) reported the total population density of earthworms (No m^{-2}) to be 205±30.4, 363±49.93 and 1264±323.18 in three different agro ecosystem, *i.e.* agro-forestry, intensive and traditional.

In the present study the density (No m^{-2}) of earthworms in cropland site was found to be in the range of 40±15.14 to 750±86.55. The values of the present investigation are more than those of Madge (1969) and Block and Banage (1968). The density of earthworms in this tropical sampling site are comparable to the values obtained by Bornebusch (1930), Reynoldson (1955) from temperate soil, Dash

and Patra (1977) from tropical soil and Tian *et al.*, (2000) in degraded Alfisol in south western Nigeria.

The expression of soil animal population in terms of biomass is more meaningful than numbers (Edwards, 1962). Biomass is equivalent to the term standing crop. In the present investing the biomass estimate ranged from 10.68±0.68 to 147.12±8.81g live wt m^{-2} in cropland site. This value is much higher than those of many European grassland and forest soils. The values are higher than the values obtained by Block and Banage (1968) in Ugandan soil and Madge (1969) in Nigerian grassland. Gonzales *et al.*, (1996) reported biomass for three different forest types to be 30.80±1.8, 29.50±1.4, 61.4±2.0g live wt m^{-2} in Puerto Rico. Bisht *et al.*, (2003) reported that biomass of earthworms ranged from 1.8 to 11.0g live wt m^{-2} in the maize crop, and from 3.4 to 16.9g live wt m^{-2} in wheat and mustard crop. Martinez *et al.* (2006) reported earthworm biomass to be 74.9 g live wt m^{-2} and 98.4 g live wt m^{-2} in the pastures and forest area of Colombian Andes.

Dash and Patra (1977) estimated the biomass of Megascolecids in tropical wet grassland of India to be in the range of 6 – 60g live wt m^{-2}. Mishra (1980) estimated the biomass, in dry deciduous forest of Orissa, India between the ranges of 7.03 – 28.49g live wtm^{-2}. The biomass obtained in the present investigation is more than the values reported by Dash and Patra (1977), Mishra (1980), Mishra and Dash (1984), Mishra and Sahoo (1997) but lies in the range of values obtained by Reynolds (1971) for mixed wood population and the value is lower than that reported by Monroy *et al.*, (2006).

According to Edwards and Bohlen (1996) soil moisture can influence earthworm numbers and biomass. Wood (1974) reported a strong positive correlation between earthworm biomass and increased soil moisture content for surface soil-inhabiting earthworm species surveyed at 18 different sites on Mt. Kosciusko in South eastern Australia. In the present study also a positive significant correlation was observed between soil moisture and biomass in cropland site ($r = 0.911$, $p<0.001$), and is in conformity with the findings of above workers. The correlation observed between soil moisture and earthworm biomass further confirmed the importance of soil moisture for earthworms, even in the humid tropics. Biomass of earthworm had a significant positive correlation with relative humidity ($r = 0.853$; $p<0.05$), with rainfall ($r = 0.709$; $p<0.001$), with organic carbon content ($r = 0.903$; $p<0.05$) and with nitrogen ($r = 0.839$; $p<0.05$) in the study site.

REFERENCES

Ali, M.K., Dash, M.C. and Patra, U.C. 1973. Estimation of *Lampito mauritii* (Oligochaeta) population by chemical methods. *Science and Culture.* 39 : 558 – 560.

Bartlett, M. D.,Briones, M,J. I., Neilson, R., Schmidt, O., Spurgeon, D. and Creamer, R. E. 2010. A critical review of current methods in earthworm ecology: From individuals to populations. *European Journal of Soil Biology.* 46: 67-73.

Bisht, R., Pandey, H., Bharti, D. and Kaushal, B. R. 2003. Population dynamics of earthworms (Oligochaeta) in cultivated soils of central Himalayan tarai region. *Tropical Ecology.* 44(2): 229-234.

Block, W. and Banage, W. B. 1968. Population density and biomass of earthworms in some Ugandan soils. *Rev. Ecol. Biol. Sol.* 5(3): 515-521.

Bornebusch, C.H. 1930. The fauna of the forest soils. *Forstle. Forsoksv. Danm.* 11 : 1-224.

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

Darwin, C. 1981. The formation of vegetable mould through the action of worms with observations of their habit, John Murray, London, pp. 326.

Dash, M.C. 1978. Role of earthworms in decomposer system. In: *Glimpses of Ecology*. J.S. Singh and B. Gopal (Eds.). International Scientific Publications, New Delhi, pp. 399-406.

Dash, M.C. and Patra, U.C. 1972. A comparison of extraction methods for megascolecidae (Olig.) and Ocnerodrilidae (Olig.) from Agricultural soils of Berhampur, Orissa. *Curr. Sci.* 41: 54-55.

Dash, M.C. and Patra, U.C. 1977. Density, biomass and energy budget of tropical earthworm population from a grassland site in Orissa, India. *Rev. Ecol. Biol. Sol.* 14(3): 461-471.

Dash, M.C., Patra, U.C. and Thambi, A.V. 1974. Comparison of Primary Production of plant material and secondary production of Oligochaetes in tropical grassland of Southern Orissa, India. *Trop. Ecol.* 15 (1 & 2): 16-21.

Edwards, C.A.1962. Relationships between weights, volumes and numbers of soil animals. In: Graff, O. and Satchell, J. E. (Eds). *Progress in Soil Biology*. North Holland Publishing Company. Amsterdam. 584-594.

Edwards, C.A. and Bohlen, P. J. 1996. *Biology and Ecology of Earthworms.* 3rd edition. Chapman and Hall, London.

Edwards, C. A. and Lofty, J. R. 1972. *Biology of Earthworms.* 1st Edition, Chapman and Hall, London. pp-333.

Edwards, C.A. and Lofty, J.R. 1977. *Biology of Earthworms.* 2nd edition, Chapman and Hall, London. pp xvii + 333.

El. Duweini, A.K. and Ghabbour, S.I. 1963. A study of the

specific distribution of megadriline Oligochaetes in Egypt and it's dependence on soil properties. *IBid.* 18 : 21-30.

El. Duweini, A.K. and Ghabbour, S.I. 1965. Population density and biomass of earthworm in different types of Egyptian soils. *J. Appl. Ecol.* 2: 271-287.

Evans, A.C. and Guild, W.J. Mc. L. 1947. Studies on the relationships between earthworms and soil fertility. I Biological studies in the field. *Ann. Appl. Biol.* 34(3): 307-330.

Fragoso, C., Brown, G.G., Patro, J.C., Blanchart, E., Lavelle, P., Pashanasi, B., Senapati, B.K. and Kumar, T. 1997. Agricultural intensification, soil biodiversity and agroecosystem function in the tropics : the role of earthworm. *Applied Soil Ecology.* 6: 17-35.

Gates, G.E. 1961. Ecology of some earthworms with special reference to seasonal activity. *Am. Midl. Nat.* 66: 61-86.

Gerard, B.M. 1967. Factors affecting earthworms in pasture. *J. Ani. Ecol.* 36: 235-252.

Gonza'lez, G., Zou, X. and Borges, S. 1996. Earthworm abundance and species composition in abandoned tropical croplands: comparisons of tree plantations and secondary forests. *Pedobiologia.* 40: 385-391.

Haokip, S.L. and Singh, T.B. 2012. Diversity and distribution of earthworms in a natural reserved and disturbed subtropical forest ecosystem of Imphal – West, Manipur, India. *International Multidisciplinary Research Journal.* 2(2): 28-34.

Jones, C.G., Lawton, J.H. and Shachak, M. 1994. Organisms as ecosystem Engineers. *Oikos.* 69 : 373-386.

Joshi, N., Dabral, M. and Maikhuri, R.K. 2010. Density, Biomass and species richness of earthworms in Agroecosystems of Garhwal Himalaya, India. *Tropical Natural History.* 10(2): 171-179.

Julka, J. M. and Paliwal, R. 2005. Distribution of earthworms in different agro climatic region of India. In : Ramakrishnan, P. S., Saxena, K. G., Swift,K G. and RauksMaikhri,R. K. (Eds.). *Soil Biodiversity, Ecological Processes and Landscape*, Oxford and ABH Publication Co. Pvt. Ltd., New Delhi, pp 3-13.

Kale, R.D. 1998. *Earthworms: Cindrella of Organic Farming*. Prism Books Pvt. Ltd. Bangalore, India.

Kale, R.D. and Krishnamoorthy, R.V. 1982. Cyclic fluctuations in the population and distribution of three species of tropical earthworms in a farm yard garden in Bangalore. *Rev. Ecol. Biol. Sol*. 19 : 61-71.

Karmegam, N. and Daniel, T. 2007. Effect of physico-chemical parameters on earthworm abundance: A quantitative approach. *Journal of Applied Sciences Research.* 3: 1369-1376.

Lavelle, P. 1978. Les vers de terre de la savanna de Lampto (Cote d Ivoire): peuplents, populations et functions dans L ecosystems. *Publ. Lab. Zool. E. N. S.* 12: 301.

Madge, D.S. 1969. Field and Laboratory studies on the activities of two species of tropical Earthworms. *Pedobiologia.* 9 : 188-214.

Martinez, A. F., Quintero, H. and Fragoso, C. E. 2006. Earthworm communities in forest and pastures of the Columbian Andes. *Caribbean Journal of Science.* 42(3): 301-310.

Mishra, P.C. 1980. *Ecophysiological studies on tropical earthworm (Density, biomass, feeding biology, metabolism, digestive enzymes and their role in soil)*. Ph.D. thesis submitted to Sambalpur University, Orissa, India. pp. 109.

Mishra, P.C. and Dash, M.C. 1984. Population dynamics and respiratory metabolism of earthworm population in a subtropical dry woodland of western Orissa, India. *Trop Ecol.* 25 : 103-116.

Mishra, P.C. and Sahoo, S. 1997. Production and energetics of earthworm population (*Lampito mauritii*, Kinberg) and metabolism in soil under paper mill waste water irrigation. *Ecol. Env. & Cons.* 3(1): 49-61.

Mishra, P.C., Satpathy, G.R., Patnaik, H.K. and Dash, M.C. 1985. Effect of malathion treatment on soil metabolism of a tropical grassland ecosystem of Orissa, India. In: *Verms and Vermicomposting,* Dash, M.C., Senapati, B. K. and Mishra, P.C. (Eds.) Five Star Press, Burla, Sambalpur. pp. 148-55.

Monroy, F., Aira, M., Dominguez, J. and Velando, A. 2006. Seasonal population dynamics of *Eisenia foetida* (Savigny, 1826) (Oligochaeta, Lumbricidae) in the field. *C. R. Biologies.* 329 : 912-915.

Nakamura, Y. 1968. Studies on the ecology of terrestrial Oligochaetae. 1. Seasonal variation in the population density of earthworms in alluvial soil grassland in Sapporo. *Jap. J. Appl. Ento. Zool.* 3 : 89-95.

Nurhidayati, A. E., Suprayog, D. and Hairiah, K. 2011. Long term impact of conventional soil management to earthworm diversity and density on sugarcane plantations in East Java, Indonesia. *Journal of Nature Studies.* 10(2): 16-25.

Reynolds, J. W. 1971. The effects of altitude, soil moisture and soil acidity on earthworm (Oligocheta: Acanthodrilidae and Lumbricidae) density, biomass and species diversification in *Liriodendron tulipifera* L. stands in two areas of cast Tennessee. *Ibid.* 18 : 52

Reynoldson, T. B. 1955. Observation on the earthworms of North Wales. *N. West Nat.* 3: 291-304.

Satchell, J.E. 1955. Some aspects of earthworm ecology In: *Soil Zoology,* Kevan, D.K. & Butterworths, Mc. E. (Eds.), London. pp. 180-201.

Satchell, J. E. 1967. *Lumbricidae.* In: *Soil Biol.* Burges, A. and Raw, F. (Eds.) Acad. Press, Lond. pp. 259-322.

Sathianarayanan, A. and Khan, A. B. 2006.Diversity, distribution and abundance of earthworms in Pondicherry region. *Tropical Ecology.* 47 (1): 139-144.

Senapati, B. K. and Dash, M. C. 1981. Effect of grazing on the elements of production in the vegetation of oligochaeta components of a tropical pasture land. *Rev. Ecol. Biol. Soil.* 18 (4): 487-505.

Senapati, B. K. and Dash, M. C. 1984. Influence of soil temperature and moisture on the reproductive activity of tropical earthworms of Orissa. *Journal of Soil Biology and Ecology.* 4: 13-21.

Sims, R. W. and Gerard, B.M. 1999. *Earthworms,* FSC Publications, London.

Sinha, M.P. and Srivastava, R. 2001. Seasonal variation in density and biomass of earthworms *Perionyx sansibaricus* Michaelsen in garbage dumping site at Ranchi, India. *SUJST. Vol XIII. Sec. A.* pp. 64-68.

Sinha, M.P., Srivastava, R., Kumar, M., Gupta, D. K. and Sen, N. S. 2003. Population biology and reproduction strategy of *Ocnerodrilus occidentalis* (Oligocheta: Ocnerodrilidae) from Tropical agroecosystem at Ranchi, India. *Trans. Zool. Soc. East. India.* 7(2): 33-41.

Srivastava, R. 2002. *Some aspects of ecological investigation on earthworm with reference to climo edaphic factors.* Ph.D. thesis submitted to Ranchi University, Ranchi, India. 163-164.

Srivastava, R., Gupta, D. K. and Sinha, M.P. 2012. Monthly variation in the density of *Drawida willsi* (Michaelsen) in relation to some climatic and edaphic factors. *Nature Environment and Pollution Technology*. 11(4): 725-728.

Tian, G., Olimah, J. A., Adeoye, G. O. and Kang, B. T. 2000. Regeneration of earthworm populations in a degraded soil by natural and planted fallows under humid tropical conditions. *Soil Science Society of American Journal.* 64: 222-228.

Timmerman, A., Bos, D., Ouwehand, J. and Goede, R.G.M. de. 2006. Long term effects of fertilization regime on earthworm abundance in a semi natural grassland area. *Pedobiologia.* 50: 427-432.

Tripathi, G. and Bhardwaj, P. 2004. Earthworm diversity and habitat preferences in arid regions of Rajasthan. *Zoos Print Journal.* 19(7) : 1515-1519.

Tondoh, J. E. and Lavelle, P. 2005. Population dynamics of *Hyperodrilusafricianus* (Oligochaeta: Eudrilidae) in Ivory Coast, West Africa.

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

Wood, T.C. 1974. The distribution of earthworms (Megascolecidae) in relation to soils, vegetation and altitude on the slopes of Mt. Kosciusko, Australia. *J. Anim. Ecol.* 43: 87-106.