DIVERSITY OF EARTHWORMS AND THE IMPACT ON SOIL FERTILITY IN A SUB-TROPICAL FOREST ECOSYSTEM OF MOKOKCHUNG DISTRICT, NAGALAND.

THESIS SUBMITTED IN PARTIAL FULLFILMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN ZOOLOGY TO NAGALAND UNIVERSITY.

By
LILONGCHEM THYUG
Ph.D. Registration No.527/2013

DEPARTMENT OF ZOOLOGY
SCHOOL OF SCIENCES
NAGALAND UNIVERSITY
Headquarters:Lumami

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Department of Zoology

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Headquarters-Lumami

P.O.Lumami-798627

Certificate

This is to certify that the thesis entitled "Diversity of Earthworm and the Impact on Soil Fertility in a Sub-Tropical Forest Ecosystem of Mokokchung District,Nagaland" incorporates the results of the original findings carried out by **Mr. Lilongchem Thyug** under my guidance and supervision. He is a registered Research Scholar (Regd. No.527/2013) of the Department and has fulfilled all the requirements of Ph.D. regulations of Nagaland University for the submission of his thesis.

The work is original and neither the thesis nor any part of it has been submitted elsewhere for the award of any degree or distinction. The thesis is therefore, forwarded for adjudication and consideration for the award of degree of Doctor of Philosophy in Zoology under Nagaland University.

Dated: ___ May, 2019
Place:Lumami

Head
Department of Zoology

Prof. L. N. Kakati
Supervisor

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(Lilongchem Thyug)

Declaration

I hereby declare that the thesis entitled "**Diversity of Earthworms and the Impact on Soil Fertility in a Sub-Tropical Forest Ecosystem of Mokokchung District, Nagaland**" submitted by me is entirely the research work of my own. The thesis or part of it thereof has not been submitted elsewhere for any research degree or distinction.

Date: ___ May, 2019

Place: Lumami

(Lilongchem Thyug)

Ph.D. Regd. No. 527/2013

Department of Zoology

DEDICATION

To my wife - You kept me going

And

My children - You always motivated me.

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Chapter-I

INTRODUCTION

Earthworms are one of the key macrofaunae of soil and have been suggested as useful indicators of the health of soil ecosystems (Edwards and Bohlen, 1992) due to their role in soil fertility through fragmentation and mixing of the soil with mineral particles, promoting microbial activity and also in the breakdown of plant organic matter. Since long they have been known as "Farmer's friend" and "Nature's best fertilizers". In fact, it was Aristotle who first pointed out the role of earthworms in turning over the soil and rightly called them "The Intestines of the Earth". The ecology and the biology of the earthworms have been studied since Darwin's scientific explanation of their true role in the ecosystem and led to an upsurge of interest in earthworms study from the late nineteenth century onwards (Michaelsen, 1900; Beddard, 1912; Stephenson, 1923, 1930; Bahl, 1950).

Earthworms are very popular soil-inhabiting organisms possessing a cylindrical body with marked external and internal metameric segmentation. They exhibit great variation in size with length ranging from millimeters- American Log worm (*Bimastos parvus*) to more than a meter- Gippsland earthworm of Australia (*Megascolides australis*) (Coleman *et al.*, 2004). The smallest known earthworm is ***Chaetogaster annandalai*** which reaches a length of only 0.02 inches (0.05 cm). The Giant Earthworms, of which *Michrochaetus rappi* is the largest, measures a length of about 54 inches (1.36 m) on an average. The largest recorded being 22 ft (6.7 m) with a diameter of 0.8 inches (2 cm) (Haokip and Singh, 2012). *Drawida nilamburensis*, the biggest Indian worm measures about 1 meter and *Bismastos parvus* and *Microscolex phosphoreus* are the smallest worms measuring only about 10 mm long.

On the basis of physiology, feeding habit and burrowing-cum-casting activities, earthworms are grouped into three ecological categories *viz.*, epigeic, endogeic and anecic (Edwards and Bohlen, 1996; Hendrix and Bohlen, 2002). Epigeic worms are litter feeders, manure dwellers, tolerant to disturbances, non-burrowing surface living species producing casts over the surface, having a high rate of cocoon production and short life cycle, small body size and deeply pigmented. Geophagous endogeic species are dwellers of topsoil rich in organic matter, tolerant to some disturbances, moderate to high rate of cocoon production, light pigmented and form horizontal, complicated burrows, feed chiefly in the rhizosphere in the subsoil and produce casts generally below the ground. They are active in spring and fall but generally enter a resting state in summer and winter. As the soil starts to heat up and dry out in late spring, the endogeic species move a little deeper (perhaps 18 inches), whorl up in a ball, and produce mucus to try to keep from drying out. Anecic earthworms are phytogeophagous species producing deep vertical burrows in mineral soil, intolerant to disturbances, low rate of cocoon production, long life cycle, body size large and unpigmented or light pigmented but important for browsing and burial of surface litter and casting at the soil surface. The anecics also have a tendency to be more active in spring and fall, but they may not go into a complete latent state in summer or winter. These major ecological groups have different effects on soils and their variable ecologies suggest that their responses to disturbance may differ greatly and may alter biogeochemical processes (Lee, 1985; Edwards *et al.,* 1995; Bohlen *et al.,* 1997; Hendrix and Bohlen, 2002; Hale *et al*., 2005). However, according to Kale and Krishnamoorthy (1978), such distinction into three ecological types for the earthworms of tropics is not possible, because the greater part of earthworms in the region is geophagous, i.e., the endogeic and only a few detrivorous.

Climatic status, as well as biotic factors, strongly influences the richness and distribution of earthworms (Werner *et al.,* 2005). The number and biomass of earthworms vary significantly among the sites and among the seasons, thus indicating that climate and soil physicochemical characteristics play a major role in earthworm communities (Najar & Khan, 2011). A variety of physico-chemical factors such as soil texture, soil moisture, food, pH, temperature, soil depth, organic content, carbon, nitrogen, phosphorus, potassium and calcium are highly responsible for the distribution, abundance, diversity and biomass of the earthworms (Phillipson *et al*., 1976; Lavelle, 1983; Baker *et al*., 1993; Kale, 1998; Whalen *et al*., 1998; Lavelle *et al*., 1999). Water is the chief constituent in the earthworms' body with about 75% to 90 % of water by fresh weight. A lot of earthworms' activity depends upon the moisture content of the soil, though moisture requirements for different species vary considerably. Lack of moisture causes earthworms to diapauses thus affecting their activity (Gerard, 1960) and maximum population density of earthworms occur in soils containing moisture between 12 % and 30 % (Olson, 1928). For instance, an increase of earthworm population density of endemic species *Octolasion cyaneum* in the Himalayas from summer to rainy season indicates the positive role of moisture in influencing earthworm population (Rajwar *et al.,* 2018). Earthworms respire through the skin which needs to be kept moist in order to dissolve the oxygen. Further, the fecundity of earthworms is greatly influenced by moisture (Edwards and Lofty, 1972). Although earthworms thrive best in wet soil; they also have this distinctive ability to endure desiccation by undergoing diapauses to avoid water loss and to respond to extreme temperature conditions. Hence, prolonged droughts markedly decrease the size of earthworms, and populations may take two years to recover when conditions become favorable. Blanchart and Julka (1997) have also recorded a higher number of earthworms during wet periods. Population distribution, as well as the activity, behavior, metabolism, growth and reproduction of earthworm, are greatly affected by soil temperature. When the temperature dips too low or soars very high they usually burrow deep into the soil, the body curls into a slime cocoon ball and drop metabolic activities to bare minimum and undergo hibernation. The fecundity rate of worms is very high but can be killed by extreme temperatures. For instance, it has been suggested that earthworm populations in arable soils in the United States may be harmed by frost (Hopp, 1947) and that the worms show evidence of vertical migration. Earthworms are generally observed in the upper (0-10cm) soil layer during the rainy season but tend to penetrate deep into the soil with approaching winter (Reddy, 1983). Majority of earthworms are found in the top layer (0-15 cm), because along with the increase of soil depth, the amount of soil oxygen declines that limits the distribution of earthworms (Curry and Cotton 1983) and the deeper layer beyond 30 cm is not suitable for propagation of earthworms (Sharma and Bhardwaj, 2014). Presence of earthworm within the top 15 cm of soil layer is due to very congenial soil environment having temperature range from 25 °C - 25.8 °C, moisture content of 19.7 % - 22.4 %, water holding capacity of 26 % - 31.7 % and organic matter content of 2.4 % - 4.0 % (Dey and Chaudhari, 2014). Earthworms are very sensitive to soil pH which affects their population density and distribution. Different earthworm species react to pH in diverse ways from acidic condition to alkaline to neutral soils. While most species of earthworm are seen to prefer soils with neutral pH between 6.5 to 7.5 pH (Lee, 1985), a few others have a narrow range of either acidic or alkaline preference (Edwards and Lofty, 1977). It has been observed that species density and activity of earthworm is reduced at soil pH value below 5 and at excessively high value of over 9 (Werner *et al*., 2005).

As natural bioreactor earthworms are known to convert organic waste into organic manure. The ingested organic matter is macerated, mixed with ingested inorganic soil material, passed through the gut and excreted as a cast, which is enriched with available plant nutrients and thus enhances soil fertility. Earthworms are possibly the most significant soil organisms because of their ability to breakdown organic matters, improve soil composition and also cycle soil nutrients, particularly in dynamic ecosystems (Edwards and Bohlen, 1996; Kooch *et al.*, (2007). There is a consensus among soil ecologists and most farmers that earthworms may be one of the most outstanding indicators available in the soil to demonstrate soil quality (Doube and Schmidt, 1997). The activities of earthworm such as ingestion, burrowing, assimilation and casting help in formation of soil aggregates, aeration of the soil, improving soil water permeation and water holding capacity that ultimately improves soil structure. The role of earthworms in the decomposition process, nutrient cycling and on building and maintenance of soil structures has been well documented (Edwards and Bohlen, 1996). Hence, even though many microfaunae may be responsible for decomposition of organic matter that eventually reaches the soil, earthworms which represent a major fraction (>80%) of the soil invertebrate biomass break up the larger plant organic matter by their feeding habit. An assessment of the nutrient status of earthworm cast from the soils of temperate and tropical regions signify that earthworm casts have a superior nutrient content than the adjoining soil (Bossuyt *et al.,* 2005; Singh *et al.,* 2016). A positive relationship between earthworms and soil P content underlines the significance of earthworm activities in P cycling (Nuutinen *et al.,* 1998). Earthworms require carbon and nitrogen for their growth and reproduction, which they obtain from litter, grit and microbes and their distribution and population dynamics depend on physical conditions including water content and availability of organic matter and C**:** N ratio in an ecosystem. A large amount of nitrogen can enter terrestrial ecosystems instantaneously through the earthworm biomass which is positively correlated with both total soil C and N on a gm^{-2} basis, as well as C and N, stored in micro aggregates and the silt and clay fraction (Fonte *et al.,* 2009). Earthworm survival and growth has a positive linear increase in soil mineral-N and microbial biomass N concentrations (Eriksen-Hamel and Whalen, 2007). Earthworms also accelerate carbon activation and facilitate carbon sequestration generating an earthworm mediated 'carbon trap' in their burrows (Zhang *et al.,* 2013). Thus, soil carbon and earthworms are important components in sustainable tropical agro-ecosystem. Further, earthworms are instrumental in forming soil aggregates in various ways such as by production of gums (Swaby, 1950) or calcium humate (Meyer, 1943), by plant residues (Ponomareva, 1953), or by polysaccharide molecules (Parle, 1963).

Soil is home to several kinds of animals including different types of earthworms and many a time, their significant contribution to soil health, below ground diversity, and more broadly to ecosystem functioning have often been overlooked (Wardle, 2002; Wardle *et al*., 2004; Louw *et al.,* 2014). It enhances porosity in the soil by creating macro pore. The burrows and pores so produced by the earthworm increase the infiltration rate greatly (Slater and Hopp, 1947; Carter *et al.,* 1982). These permanent burrows can persist longer period even after the death of the earthworm and help in retention of soil moisture, particularly in heavy rainfall area. Earthworms can considerably alter the physical, chemical, and biological properties of soil (Blouin *et al*., 2013). Hence, earthworms occupy a very important position in regulating soil fertility and also help plant growth through nutrient cycling and water infiltration (Lavelle *et al.,* 2006; Don *et al.,* 2008; Deepthi and Kathireswari, 2016). There is also significant proof from pot experiments that earthworms can enhance plant growth (Mayilswami and Reid, 2010; Khomami and Zadeh, 2013; Palacios *et al.,* 2014). The earthworm *Aporrectodea longa* and *Lumbricus terrestris* increases the growth of wheat (van Rhee, 1965), *Aporrectodea caliginosa* enhances the growth of oat plants (Altavinyte and Pociene, 1973), *Allobophora parva* increases the growth of barley plants (Temirov and Valiakhmedov, 1988), *Millsonia anomala* is found to augment maize growth (Spain *et al.,* 1992), *Pontoscolex corethrurus* increases seedling growth of tropical fruit trees *Bixa orellana* and *Eugenia stipitata* (Pashanasi *et al.,* 1992), *Aporrectodea trapezoides* increases the shoot weight of wheat seedlings and wheat grain yield (Stephens *et al*., 1994; Baker *et al*., 1995; Stephens and

Davoren, 1995) and *Metaphire posthuma* improves maize and wheat growth (Dalakoti, 2015). In fact, earthworms are found to be valuable in land recuperation, soil development and organic waste management (Harender and Bhardwaj, 2001). It is observed that annual crops are comparatively critical for soil macrofauna and have low earthworm biomass in fields following annual cropping (Lee, 1985; Joshi *et al*., 2010).

Earthworms are extensively distributed throughout the world predominantly in the temperate and tropical regions and their population put in about 80 % of the total biomass of the soil (Nainawat and Nagendra, 2001). Species diversity of earthworms in tropical rain forest ranges from 1.7 to 6.5 (Fragoso and Lavelle, 1992) and the number of species in a given community is the simplest measure of diversity (Edwards and Bohlen, 1996). They are among the most significant components of soil biota in terms of soil development, preservation of soil structure and fertility (Bhadauria and Saxena, 2010). Reynolds (1994) accounted for the occurrence of 3,627 terrestrial earthworm species worldwide, with 68 species being annually added on an average. Tripathi and Bhardwaj (2001) accounted for more than 4200 known species of Oligochaetes worldwide, out of which 280 belong to Microdrili group and remaining about 3200 belongs to Megadrili (earthworms). Sinha (2009) also reported that earthworms are widely distributed throughout the world and more than 4400 species of earthworms each with their unique physical, biological and behavioral characteristics are described worldwide. The populations of earthworms are exceptionally variable in size ranging from a few individuals to more than 1000 m^{-2} and can double their population in one month in ideal conditions of temperature, moisture and food *i.e.* organic matter (Harender and Bhardwaj, 2001). Forest systems are often reported to have a greater number of earthworm species compared to cultivated agricultural land because these systems tend to be more complex and have more niches which allow persistence of a greater number of species with variable ecologies (Lee, 1985; Edwards *et al.*, 1995). In sub-tropical and tropical regions there is a wider variant of species rather than species richness (Kale and Seenappa, 1997). In 3 successional fallows after slash and burn agriculture at an elevation of 960m of Meghalaya, Mishra and Ramakhrishnan (1988) observed that different species of earthworm has different patterns for population fluctuation which are related to soil temperature, moisture and litter fall pattern of the system.

The Indian earthworm fauna is predominantly represented by native species, which constitute about 89% of total earthworm diversity in the country (Julka and Paliwal, 2005). According to Julka (1993) the Indian subcontinent (including Andaman and Nicobar islands) has 509 species under 67 genera and 10 families (Acanthodrilidae-34 species, Almidae-4, Criodrilidae-1, Eudrilidae-1, Glossoscolecidae-1, Lumbricidae-16, Megascolecidae-93, Octochaetidae-145, Moniligastridae-98, Ocnerodrilidae-16) which point to the fact that the degree of diversity in this region is higher in comparison to other areas. He also cited that the greater part of them are endemic belonging to 47 genera and that the remaining 20 genera are peregrine, which is being inertly introduced generally by man. Bhatnagar and Palta (1996) have reported 509 earthworm species from India. However, Julka and Paliwal (2005) have also listed the presence of nine families with 69 genera and more than 418 species from India. However according to Dash (2012), at present, the Indian earthworm fauna comprises about 408 species placed in 10 families and 69 genera. Thirty-eight genera are endemic on the mainland and 20 are peregrine that has been introduced to this region presumably in the soil around the roots of exotic plants.

Earthworm diversity in India is primarily due to its geographical location with a wide latitudinal range (between 8.4°N and 37.6°N), complex topography, and varied climate changes along with varietal land use pattern have directly affected the composition and population structure of earthworm species in different agro-climatic regions of the country (Blanchart and Julka, 1997; Behera *et al.*, 1999; Bhadauria *et al.*, 2000). Except in certain very harsh regions, they are found in all types of soil in varying numbers with sufficient moisture and food supply (Ghosh, 1993). Singh (1997) reported the occurrence of seven to 11 species of earthworm from cultivated, non-cultivated, grassland, garden and sewage soils. Dey and Chaudhary (2014) reported the presence of 16 species of which 5 species (*Metaphire houlleti, Metaphire posthuma, Perionyx excavatus, Amynthas alexandri* and *Pontoscolex corethrurus*) were exotic species and the rest were endemic to the Indian subcontinent**.** The numbers of species present in the rehabilitated ecosystems of Garhwal Himalayas ranged between 2 to 5 (Bhadauria and Saxena, 2018). Goswami (2018) also observed the highest number of species and genera in the residential areas (7) with the least in grassland habitat (4). The diversity value is also highest in the residential areas with the lowest in grassland habitat. This is attributed to the different organic inputs, *viz*., the inclusion of kitchen drainage and organic fertilizers of waste management which enriches the soil layers along with moderate moisture released from the daily livelihood of human beings.

Studies on earthworms in Orissa has been done by Mishra and Dash (1984); Garhwal Himalaya by Joshi *et al*. (2010); central Himalaya by Bhadauria *et al*. (2012, 2014) and South India especially in Tamil Nadu by Ismail *et al*. (1990) and Karmegam and Daniel (2000, 2001); Karnataka by Kale and Krishnamoorthy (1978) and Puducherry by Sathianarayanan and Khan (2006). A total of 40 different species of earthworms (Megascolecidae-13, Moniligastridae-10, Octochaetidate-5, Lumbricidae-4, Ocnerodrilidae-4, Acanthodrilidae-1, Alimide-1, Eudrilidae-1 and Glossoscolecidae-1) were recorded by Kathireswari *et al*. (2006) from different habitats of Western Ghats in Tamil Nadu wherein they also reported that the biodiversity of earthworm is more affected by the land use pattern. In North East India, earthworm studies are mostly concentrated in Assam (Rajkhowa *et al.*, 2015), Manipur (Stephenson, 1921; Haokip and Singh, 2012, 2017), Mizoram (Lalthanzara *et al*., 2011), Arunachal Pradesh, Sikkim (Gates, 1972 and Julka, 1988) and Tripura (Chaudhuri *et al*., 2008; Chaudhuri and Nath 2011; Dey and Chaudhuri, 2014).

Nagaland, the 16th state of Indian union covers a geographical area of 16,579 Sq. Km. and lies between 25°60” and 27°40” North latitude and 93°20” and 95°15” East longitude. The state is bounded by Assam in the North and West, by Myanmar and Arunachal Pradesh in the East and by Manipur in the South. The landscape of Nagaland is much diverse, full of hills and mountain ranges, broken up by a huge mix of wide spurs and ridges. Geographically, the state largely has vast rising and falling terrain and hilly landscape and some low lying areas giving rise to a very favorable environment with the existence of continual water sources and humidity for a truly flourishing range of flora and fauna. The state is part of the bio-geographic tri-junction of the Indian, the Himalaya and the oriental landmasses. The varied climatic regimes offer different types of vegetation- tropical rain forests in the lowlands bordering Assam, sub-tropical forests in the majority of the state and temperate forests in the Saramati, Phek regions, etc. This natural variation along with the altitudinal differences plays a major distribution of animal species in the state. Due to the state’s traditional practice of *jhum* (slash and burn) cultivation, there has been random obliteration of the forest ecosystem in recent times and result in destroying of the habitat of many animals including soil fauna. Large scale destruction of natural forest severely affects the diversity of earthworms and slash and burn system has been found responsible for the reduction of original forest species of earthworms (Bhadauria and Ramakrishnan, 1991; Darlong and Alfred, 1991). Being an agriculture-dependent state and with the rampant practice of *Jhum* cultivation, there is a necessity and urgency to have elaborate information pertaining to earthworms in Nagaland and the impact it may have on soil sub-system. While considerable reports on earthworm species and their diversity are available from mainland India including certain North Eastern states like Arunachal Pradesh, Meghalaya, Tripura, Manipur and Sikkim, there is no study or report about earthworm fauna in Nagaland except for the recording of *Drawida nagana* from Khezhakenoma area (Gates, 1945) when Nagaland was under the erstwhile Assam province. Hence a detailed comparative study was undertaken in three different sub-systems *i.e.* undisturbed natural reserve forest, community plantation area (tree plantation) and *Jhum* (shifting cultivation) fallow land area of subtropical forest ecosystem located in Mingkong area of Mokokchung district with the following objectives:

I. Earthworm resources in relation to some physico-chemical parameters in the three different sub-systems.

II. Species composition and depth distribution of earthworms in the three sub-systems

III. Monthly and seasonal population dynamics of earthworm (density and biomass), species-wise in three sub-systems.

IV. Earthworm Community characteristics (*viz.*, Diversity, Distribution, Dominance, species richness index, similarity index, etc.) of earthworms in three sub-systems.

V. Laboratory based experiments to investigate the effect of dominant earthworm on crop growth.

Chapter-II

REVIEW OF LITERATURE

The massive taxonomic information on Oligochaeta providing the systematic of earthworms has been available in "Fauna of British India" (Stephenson, 1923). Earthworms prefer medium textured soils than sandy or clayey soils and populations are regulated significantly by moisture (Evans and Guild, 1947; Guild, 1948). In Nagaland, Gates (1945) has reported the presence of *Drawida nagana* from Khezhakhenoma village which is presently located in the Phek district of Nagaland. The present chapter deals with the review of literature of recent times published from different part of the world including India particularly on distribution, diversity and population dynamics of earthworms in relation to various physico-chemical and climatic factors.

Earthworm studies in general

Evans and Guild (1947) observed that moisture is a vital regulating factor for earthworm population; however, Murchie (1958) while studying in an upland forest soil of Southern Michigan, USA, opined that interaction of a number of factors rather than a single factor was expected to influence the horizontal and vertical distribution of earthworms. Bahl (1950) reported that earthworms are normally established in the top 45 cm soil layer and also observed that it can migrate and burrow deeper up to 3 meters. Waters (1955) illustrated that seasonality of food supply in the form of root debris during late summer to early winter along with favourable climatic conditions increased the earthworm biomass and numbers in pastures of New Zealand. Gates (1961) reported that earthworms were active in the spring and autumn months during the humid continental climate and shown to hold more plant nutrients than the soil matrix itself but lesser than the plant litter (Parle, 1963). In a study from Egypt, Duwieni and Ghabour (1965) recorded 8-788 nos. m^{-2} of earthworm population and observed that the corresponding increase in the organic carbon and proportions of sand and gravel was associated with the increase of earthworm populations. Gerard (1967) stated that the vertical distribution of each species of earthworm changed considerably with the time of year. He also reported that low moisture and high temperature resulted in a seasonal mortality rate of earthworms and also showed that temperature affected the incubation time of *Allobophora chlorotica* in European conditions. While working in the grassland of Japan, Nakamura (1968) recorded the highest population of earthworm during autumn, especially in October and very low in winter, particularly during January and February. Block and Banage (1968) recorded a population size between 7.4 m^{-2} and 101.8 m^{-2} in Ugandan soils. In Nigerian grasslands, Madge (1969) recorded earthworm population size of 33 m^{-2} and established that organic content was elevated in worm cast in contrast to adjoining soils and also observed that 13.3% moisture level was favourable to produce casts. From different grassland sites in Tennessee, USA, Reynolds (1973) recorded variable earthworm biomass (fresh weight) of 3-169g^{-2}. Sharpley and Syers (1976) concluded that not only were the worm casts richer insoluble inorganic phosphates but also in exchangeable phosphorus. Edwards and Lofty (1978) reported that in uncultivated soils with growing cereals earthworm burrows provide channels for root growth which are lined with more available mineral nutrients than the adjoining soils. Phillipson *et al.* (1976) and Baker *et al.* (1993) have also reported that difference in various chemical properties, *viz.*, organic C, N, P, K, etc. are factors responsible for the distribution and abundance of earthworms in the soil of an area. Swift *et al.* (1979) reported that factors detrimental to earthworm activity in peat among others include low pH, high moisture content, and a poor quality litter of high C/nutrient ratio, low N content and low palatability, a trait similar to phenolic compounds. Gerard and Hay (1979) reported that tillage has a negative impact on earthworm density and biomass and stated that usually the greater the intensity and occurrence of disturbance the greater the effect. While working in semi-arid agricultural soil in Egypt, Ghabbour and Shakir (1982) observed that an increase in organic carbon content was associated with increased numbers and biomass of earthworms. The change in the population structure of earthworm species due to disturbance of natural forest has been reported by Satchell (1983) for temperate regions and by Fragoso and Fernandes (1994) for tropical regions. Mackay and Kladivko (1985) also concluded that the intensity and frequency of disturbances negatively affected the biomass and density of earthworms. Lee (1985) also viewed that earthworm diversity is higher in natural systems than in disturbed habitats. As he observed, some species such as *Amythas corticis* colonizes disturbed sites worldwide outside their historical range of presence due to their ability to tolerate varying soil temperature, moisture, and pH and stated that optimum soil moisture content differs from species to species indicating the capacity of the earthworms to adapt to local conditions. Parmelee and Crossley (1988) documented that earthworm populations and biomass are significantly influenced by soil temperature and moisture, and in temperate agro-ecosystems, earthworms were usually most active during spring and autumn. They also reported that the expressed role of earthworms in the C and N cycle can be measured by knowing the estimates of earthworm secondary production. Lavelle and Pashanasi (1989) observed that the pastures of cleared forest in Peruvian Amazonia comprised almost entirely of the endogeic peregrine species *Pontoscolex corethrurus* showing the high density and biomass of 474–573 ind/m^2 and 78–116.4 g/m^2 in traditional pasture and 546–740 ind/m^2 and 103.2–153 g/ m^2. in improved pasture. Species richness of earthworms has been extensively studied in various habitats (Baker *et al.*, 1993; Valle *et al*., 1997; Mele and Carter, 1999; Curry *et al*., 2002; Haynes *et al*., 2003; Rossi and Blanchart, 2005). Earthworms also enhance the amount of nitrogen mineralized from organic matter in the soil (Syers *et al.*, 1979; Ruz Jerez *et al.*, 1988). Edwards and Lofty (1982) stated that annual N application to cereals for more than 130 years amplified earthworm population growth in proportion to the quantity of N applied. While working in wide variety of soil-vegetation types with varied management histories in the state of Georgia, Hendrix *et al.* (1992) highlighted a very high significant correlation between earthworm populations and soil organic carbon content and concluded that earthworm on meadows infused with inorganic fertilizer had nearly twice the earthworms in average than in the unfertilized meadow of the region. Fragoso and Lavelle (1992) demonstrated that average biomass and population density of earthworms in tropical rain forests did not show much variation from that of temperate forest. Further, cultivation methods during agricultural practices are known to affect earthworm population density (Springett *et al.*, 1992; Fraser, 1994). Baker *et al.* (1993) recorded increased earthworm population from May to July and decreased from July to October and in contrast maximum density during winter and spring in Australia. Lavelle *et al.* (1994) suggested that annual crops always tend to present a depleted macroinvertebrate population. Fragoso and Fernandez (1994) reported that in tropical regions, the alteration of the natural earthworm species population structure was due to disturbance and degradation of natural forest. The earthworm populations in frequently cultivated arable soil are typically very variable and populations are intermediary in size between the more sterile habitats and those in pasture and natural grassland which can hold a larger number of earthworms (Edwards and Bohlen, 1995). Reynolds (1995) estimated 147 earthworm species in North America and concluded that the distribution pattern and species composition are found to be significantly limited by the ambient climatic condition, physical and chemical properties of soil prevailing in a specific geographical area. Edwards and Bohlen (1996) suggested that earthworms improved soil physical structure, contribute to the breakdown of organic matter and release plant nutrients, however, population density and diversity depends on food availability, soil physical conditions, climate, land use pattern and disturbance at a given locality. Additionally, earthworms increase the biomass and activity of soil microbial diversity which in turn encourage earthworm population and allow fungi to perform better (Doube and Brown, 1998). Lavelle *et al.* (1999) observed a depletion of litter feeding epigeic and anecic species of earthworm in tropical soils as compared to those in temperate soils as organic matter decomposed at a quicker rate when temperatures are higher which results in poor availability of litters.

Fragoso *et al.* (1999) reported that the structural composition in the earthworm communities varied depending upon the type of agroecosystems and suggested that species number was the easiest measure of species diversity. James (2000) reported that soil moisture affects earthworm abundance, activity patterns and geographic distribution. They also suggested that soil temperature controls the seasonal activity thereby limiting earthworms during humid and freezing periods and indicated that soil pH is often cited as a limiting factor on earthworm distribution. From Egyptian soil, Schmidt & Curry (2001) reported low population density of earthworm with a low moisture content of the soil, while Schmidt *et al.* (2004) demonstrated that with the increase in organic carbon content earthworm density also increased. Decaens *et al.* (2004) in their study in Seine Valley (Upper Normandy, France), reported that the composition, distribution and diversity of earthworm population are chiefly determined by soil moisture, pH, organic carbon and nitrogen of different soil types. Edwards (2004) observed that earthworm feeding influenced the progressive fall of carbon-nitrogen ratio in the organic matter, transformed the bulk of nitrogen into the ammonium or nitrate form and the other soil nutrients like phosphorus and potassium are also altered into forms which are easily available to plants. Eriksen-Hamel and Whalen, (2006) reported that earthworm development is influenced by variation in soil temperature and moisture and may, therefore, be used as a pointer for earthworm build up under field conditions. Weihua and Xiuqin (2007) studied the transformation of organic carbon and total nitrogen in the broad leave litters ingested by earthworms. Smetak *et al*. (2007) reported that relatively low soil moisture is of concern as earthworms are particularly sensitive to moisture stress and solely rely on soil water to stay hydrated. Kooch and Jalilvand (2008) also stated that earthworms are the most essential component of soil detritivors in temperate forests. Somniyan and Suwanwaree (2009) observed that earthworm population density was positively and significantly correlated with soil moisture, rainfall, total nitrogen and organic matter but interestingly did not correlate with temperature as well as with phosphorus, potassium and C/N ratio. Eggleton *et al.* (2009) observed declination of population density during hot and dry summer and increase in wet winter in the UK. While studying the diversity and distribution of terrestrial earthworms from a tropical forest in Thailand, Somniyan and Suwanwaree (2009) recorded the variation of species to a great extent depending upon the site and habitats, history of land use and soil disturbance. Ayuke *et al*. (2009) also reported that some earthworm groups were positively correlated with N and were found to be more abundant in the forests of Kenya. In their study in Romania, Iordache and Borza (2010) found out a negative correlation of pH and phosphorus with earthworm number and biomass and positive correlation with organic carbon and nitrogen. Mathieu *et al.* (2010) emphasized that the environmental conditions triggered the dispersal behaviour of earthworms. Kavdir and Ilay (2011) reported that size, abundance and varied behavioural activities of earthworms significantly manipulated the physical characteristics of the soil such as texture, structure, density, porosity and water holding capacity. Hristo Valchovski (2014) recorded 13 species of earthworms *viz.*, *Lumbricus terrestris, Aporrectodea caliginosa, Aporrectodea rosea, Aporrectodea caliginosa trapezoids, Allolobophora chlorotica, Octolasion lacteum, Aporrectodea longa, Eiseniella tetraedra, Aporrectodea jassyensis, Eisenia fetida, Eisenia lucens, Lumbricus rubellus* and *Octodrilus transpadanus* from the Sofia plains of Bulgaria. Kamdem *et al.* (2018) showed that land use type in different regions, as well as their interaction in Northern Cameroon, significantly affected the abundance and biomass of earthworms. Guéi *et al.* (2018) reported an increase of earthworm diversity pattern from lower to higher in accordance to three different land use types i.e. first group (primary and secondary forest- low diversity), second group (Teak and Cocoa plantation-median diversity) and third group (multispecies plantations, mixed-crop and fallow fields) respectively and highlighted that low diversity of earthworms in the primary and secondary forests attributing it to the poor quality of litter (rich in lignin) while exhibiting increase in the abundance and diversity of earthworms in the forest environment disturbed by human activities.

Earthworm Studies in India

While working in the grasslands of Berhampur, Orissa, Dash *et al*. (1974) observed a variation of approximate biomass of Megascolicidae from 6-60 g wet weight/m² with a monthly average was 30.25 g/m² (about 8g in dry weight). Dash and Patra (1977) studied the density, biomass and energy budget of earthworm population of tropical grassland in Orissa, India. Kale and Krishnamoorthy (1978) reported that the population density of earthworm species is not at all related to the organic matter of the soil. Senapati (1980) showed density and biomass ranges of 17.4–800 ind/m^2 and 30.2–56 g/m^2 in an improved pasture of India. Senapati and Dash (1983) reported an average monthly live earthworm biomass of 32 g (8 g wt /m^2) and 56 g (11 g dry wt /m^2) in the lowland and the upland pasture sites respectively of Orissa, India. Reddy (1983) demonstrated that earthworms were encountered in the upper (0-10cm) soil layer during the rainy season but tend to penetrate deep into the soil as winter approached. The Deccan Peninsula in India is rich in earthworm fauna and harbors many epigeic and anecic species such as *Dichogaster bolani, Drawida willsi, Perionyx excavates, Perionyx sansibaricus*, *Ramiella* species and *Lampito mauritii* and many of these species are prized for their exploit in vermitechnolgy (Dash and

Senapati, 1985; Dash, 1999). Julka and Senapati (1987) have listed 30 earthworm species from Orissa, India. Bhadauria and Ramakrishnan (1989) explained the annual cycle of earthworm population highlighting maximum density and biomass during rainy to early winter and minimum during the summer season and showed a declining after slash and burn cultivation. Reddy and Reddy (1990) confirmed with the upturn of earthworm biomass after the second tillage in grasslands. Ismail *et al.* (1990) studied the species richness and diversity in some selected habitats of Madras city. Bhadauria and Ramakrishnan (1991) reported that large scale destruction of natural forests severely affects the diversity of earthworms in the north-east part of India. In the same year, Reddy and Pasha (1993) observed that seasonal variation in the earthworm population size is more affected by the physical parameters of the soil together than chemical factors, however, species richness and population density are affected in a significant way by combined action of various physical and chemical factors of the soil. Bhatnagar and Palta (1996) reported that vertical distribution of earthworm varied for different seasons due to habitat preferences and feeding habits etc. Blanchart and Julka (1997) studied the influence of forest disturbance on earthworm communities in Western Ghat, South India and reported the variation in earthworm densities ranging from 35 individuals/m^2 in a Phoenix pasture to 545 individuals/m^2 in a thicket. While studying in three geographical regions of Karnataka, Kale (1997) established a declining trend in the population of earthworm from cultivated land to grassland and concluded that the distribution pattern of the earthworms and their density is intimately related to the moisture content, soil parameters, flora and the land use practices. Bhadauria *et al*. (1997) reported that under a relatively similar pattern of land management activities and with similar kind of cropping patterns, *Drawida* sp. was dominant and certain species like *Metaphire houlleti* are able to endure disturbances caused by intensive agricultural practices. Chaudhuri and Bhattacharjee (1999) showed that the different soil physic-chemical factors such as soil moisture, pH, temperature and organic matter play a vital role in the distribution and diversity of earthworms. Bhadhauria *et al.* (2000) recorded a high density and biomass of 149 m^{-2} and 4.1 g m^{-2} from the mixed forests and low density and biomass of 65 m^{-2} and 1.40 g m^{-2} from the pine forest of Central Himalayas in India. Kaushal *et al.* (1999) and Bisht *et al.* (2003) studied the population dynamics and seasonal activity of earthworms in cultivated soils of central Himalaya. Sinha *et al* (2003) reported that the distribution of earthworm functional groups is determined by land use practices. Tripathi and Bhardwaj (2004) reported 9 species of earthworms belonging to four families from Jodhpur district of Rajasthan and suggested that the distributions of earthworm were mainly dependent on the physico-chemical characteristic of the soil. Similarly, Ramanujan *et al* (2004) reported the species composition of Mizoram with the presence of 11 species distributed among four families of earthworms. Julka and Paliwal (2005) reviewed on distributions of earthworms in different agro-climatic regions of India. Sathianarayanan and Khan (2006) studied the population densities of ten species viz. *Drawida willsi, D.limella, D.scandens, Pontodrilus bermudensis, Pontoscolex corethrurus, Lampito mauritii, Perionyx excavatus, Eudrilus eugeniae, Octochaetona serrata* and *O.barnesi* belonging to seven genera and six families and their distribution pattern in Pondicherry region. Bisht *et al.* (2006) studied on feeding and casting activities of the earthworm and their effects on crop growth under laboratory conditions. Chaudhuri *et al.* (2008) studied the population distribution of earthworm in relation to physico-chemical parameters of rubber plantations in Tripura. Joshi and Aga (2009) studied the influence of various physico-chemical factors viz. moisture content, soil temperature, pH, oxidizable organic matter, nitrogen, phosphorous, potassium and calcium on diversity and distribution of earthworm in a subtropical forest ecosystem in the foothills of Shivalik Himalaya. Najar and Khan (2011) studied inter-site variation of density, distribution as well as biomass of earthworm population from Kashmir Valley and recorded and recorded eight earthworm species belonging to the three families of Moniligastridae, Megascolecidae and Lumbricidae. Lalthanzara *et al.* (2011) were of the opinion that the synergistic effect of soil physical parameters in plantations of different agroforestry sites had comparatively more influence on abundance and population dynamics of earthworms than that of the chemical components. Chaudhuri and Nath (2011) recorded ten species of earthworms from rubber plantations and their adjacent mixed forests in west Tripura. Dey and Chaudhuri (2014) showed that there are low diversity index and species evenness and a high index of dominance in the rubber plantation as compared to the mixed forests. Padashetty and Murali (2015) reported six species *viz.*, *Eisenia fetida, Dichogaster bolaui*, *Perionyx excavatus, Perionyx sansibaricus, Polypheretima elongate and Eudrilus eugeniae* from the north Gulbarga region of Karnataka. While studying the diversity and distribution of earthworm species in various soil habitat conditions of Assam, Rajkhowa *et al.* (2015) recorded *Amynthas diffringens*, *Perionyx excavates*, *Glyphidrilus gangaticus*, *Lampito mauritti* as principal dominant species under agricultural land use system and *Metaphire posthuma* and *Dichogster saliens* as dominant species under open grassland and mixed forest system. While recording six earthworm species belonging to five families from four locations of Vatakara in Kerala, Deepthi and Kathireswari (2016) emphasized that high amount of soil nutrients in the forest area as compared to the other regions play a positive role in earthworm abundance. In a comparative study between two earthworms species of *Eisnia foetida* and *Perionyx excavatus* in different agro-ecosystems, Akilan and Nanthakumar (2017) recorded more adult worms were in the rice cultivation area which was followed by turmeric, sugarcane and banana fields. Garg and Julka (2017) reported a variable pattern of species richness ranging from 2-8 species between among the different land-use types in the trans-Gangetic plains of Yamuna Nagar district in Haryana. Jamatia and Chaudhuri (2017) showed that density and biomass of earthworms, in general, had a significant positive correlation ($P < 0.05$) with soil moisture and a negative correlation ($P < 0.05$) with soil temperature. They also exhibited positive correlations ($P < 0.05$) between earthworm density and soil pH as well as with organic matter contents. Haokip and Singh (2017) made a comparative study on the earthworm community structure in the natural mixed and oak plantation sub-tropical forests ecosystem of Imphal, Manipur, India. Bhadauria and Saxena (2018) also highlighted in their studies that earthworm communities are directly affected by alteration of land use patterns. Sankar and Patnaik (2018) in their study from Odisha, identified ten species which belong to five different families *viz*., *Lampito mauritti*, *Perionyx excavates*, *Pontodrilus bermudensis*, *Perionyx gravely*, *Eudrilus eugeniae*, *Octochaetona serrata*, *Pheretima alexandri* and *Eisenia fetida*. Rajwar *et al.* (2018) reported the presence of endemic species *Octolasion cyaneum* from Kumaun Himalayas and showed that although the density of earthworm swells during the rainy season the population of *Octolasion cyaneum* did show higher abundance in summer season indicating the high impact of the population during the summer season. Senthil and Sivakami (2018) recorded earthworm diversity ranging from 6 to 10 from three locations around Tiruchirappalli, Tamil Nadu.

Chapter-III

DESCRIPTION OF THE STUDY SITES

Location

The present study was carried out in three different sites of a contiguous sub-tropical hill forest ecosystem characterised with gentle to steep slopes *viz.*, reserve forest (site I), fallow area (site II) and plantation (site III) respectively located in Mingkong area which is about 10 km away from Mokokchung town. The sampling was done from November 2014 to October 2015. These sites lie at 29° 15’- 30° 15’ North latitude and 77° 55’- 78° 30’ East longitude **(Plate No.1)** and the altitude ranges from 1400 to 1600 m above MSL.

Reserve forest vegetation

This study area basically falls under the tropical semi-evergreen type with common tree species *Atrocarpus chaplasha*, *Castanopsis tribuloides*, *Itea macrophylla, Elaeocarpus floribundus, Ficus semicordata, Schima wallichii*, *Kydia calycina, Macaranga denticulata*, *Firmiana colorata*, *Mallotus tetracocccus*, *Trema orientalis, Sapium eugeniifolium.* Shrubs like *Tephrosia candida, Vernonia volkameriifolia*, *Pavetta indica*, *Styrax serrulata*, *Abroma augusta*, *Leea macrophylla*, *Crotalaria cytisoides* are quite common in the study area **(Plate No.2 a).**

The ground flora is relatively richer with the predominance of *Phlogacanthus asperulus*, *Mycetia longifolia, Callicarpa rubella, Solanum torvum, Strobilanthes coloratus, Mussaenda macrophylla, Elatostema platyphylla, Melastoma nepalensis, Clerodendrum glandulosum, Physchotria denticulata, Justicia adhatoda, Hedychium nagamense, Larsenianthus careyanus, Hedychium stenpopetalum, Hedychium coccineum, Chloranthus elatior*, *Impatiens latiflora, Impatiens toppinii, Globba multiflora* etc. The forest is also blessed with different climbers like *Combretum acuminatum*, *Entada* *rheedei*, *Smilax zeylanica, Acacia pennata*, *Ampelocissus divaricata, Mucuna imbricata*, *Hodgsonia marcocarpa*, *Mastersia assamica*, *Paederia scandens* etc.

Wild bananas like *Musa flaviflora*, *Musa itinerans* are also quite common in the study side. Local people used to collect the inflorescence for vegetables.

The herbaceous ground vegetation is dominated by *Torenia cordifolia*, *T. violacea*, *T. diffusa*, *Begonia* spp., *Impatiens* spp., *Viola pilosa, Sonerila maculata*, *Ophoirrhza* spp., *Lobelia montana*, *Ageratum conyzoides*, *Bidens biternata*, *Cuphea balsamona*, *C. procumbens*, *Osbeckia stellata*, *Urea lobata, Sida rhombifolia*, *Triumfetta pilosa, Vernonia scandens*, *Lindernia antipoda*, *L. montana*, *L. procumbens*, *Hedyotis auricularia*, *Blumea* spp., *Justicia* spp., *Phaulopsis imbricata*, *Lepidagathis incurva*, *Anaphalis contorta*, *A. adnata*, *A. griffithii*, *Elephantopus scaber*, *Emilia sonchifolia*, *Eupatorium* spp., *Sonchus wightianus, Spilanthes calva*, *S. paniculata*, *Synedrella nodiflora*, *Vernonia cineria*, *Crotalaria* spp., *Desmodium triflorum*, *D. heterophyllum, D. heterocarpon* var. *strigosum*, *Oxalis corniculata*, *O. corymbosa*, *Phrynium pubinerve, P. placentrium*, *Alpinia malaccensis, Hedychium* spp., *Hitchenia careyana*, *Costus speciosus*, *Globba clarkei*, *G. multiflora*, *Chrysopogon aciculatus*, *Dichanthium parviflorum, Imperata cylindrica*, *Panicum khasianum*, *Setaria viridis*, *Paspalum conjugatum*, *P. paspalodies, Alopecurus arundinaceus, Arundinella nepalensis*, *A. purpurea*, *Phragmetis karka, Sporobulus piliferus, Galeola lindleyana, Eulophia zollingeri, Epipogium roseum, Anthogonium gracile*, *Spatthoglottis ixioides, Molineria capitulata*. *Aeginetia indica*, a saprophyte is also found in moist places.

Epiphytes and other climbers comprise of *Aeschynanthes parasiticus*, *A. bracteatus, A. sikkimensis*, *Agapetes salicifolia*, *Piper attenuatum*, *P. griffithii*, *P. longum, P. mullesua, P. sylvaticum, Pothos scandens*, *Remusatia hookeriana*, *R. vivipara*, etc.

Some stem parasites are *Macrosolen cochinchinensis*, *Taxillus umbellifer*, *Tolypanthus involucratus*, *Helixanthera ligustrina*, etc. Besides, the tree trunks in these forests are moss-laden and harbour multitudes of epiphytic orchids, ferns, fern-allies, bryophytes and lichens.

Fallow land

This area is mainly dominated by trees like *Macaranga denticulata*, *Mallotus tetracoccus*, *Sapium baccatum*, *Bischofia javanica* , *Ficus hirta*, *Ficus semicordata*, *Schima wallichii* etc. Shrubs flora is dominated by *Mussaenda roxburghii*, *Rubus indotibetanus*, *Melastoma malabathricum* etc. Climbers are quite common and dominated by *Dioscorea pentaphylla*, *Smilax perfoliata*, *Thunbergia grandiflora*, *Thunbergia coccinea*, *Paederia scandens* etc. Grasses like *Saccharum arundinaceum*, *Themada villosa* intermixed with *Digitaria* sp., and *Panicum* sp. are quite common in the area **(Plate No.2 b).**

Plantation

Monoculture plantation like *Gmelina arborea* is common in this area. Grasses like *Digitaria* sp., *Panicum* sp. *Saccharum arundinaceum* intermixed with *Musa markkuana* is common in this study area. *Daubanga grandiflora* is the most dominant plantation tree in the area followed by *Terminalia myriocarpa* and *Neolamarckia cadamba* **(Plate No.2 c).**

Climate

The climate of the area is monsoonal with warm moist summer and cool dry winter. The year is divisible into three season's viz. Pre-monsoon, monsoon and winter. The month of March and October are the transitional months between winter and pre-monsoon and monsoon and winter season respectively. The ombrothermic data based on ten years (2006-2016) is indicated in **(Fig. 1).** The mean maximum air temperature varied from 25.64^{0}C (January) to 30.8^{0}C (May) and mean minimum air temperature varied from 5.68^{0}C (January) to 23.03^{0}C (July). The average mean temperature ranged from 13.40^{0}C (January) to 24.70 ^{0}C (July). Minimum monthly rainfall occurred in January (22.5 mm) and maximum in July (203 mm). The area received an average annual rainfall of 1001.6 mm during the study period. Relative humidity was recorded to be at maximum in the month of August (83.21%) **(Fig. 2)**.

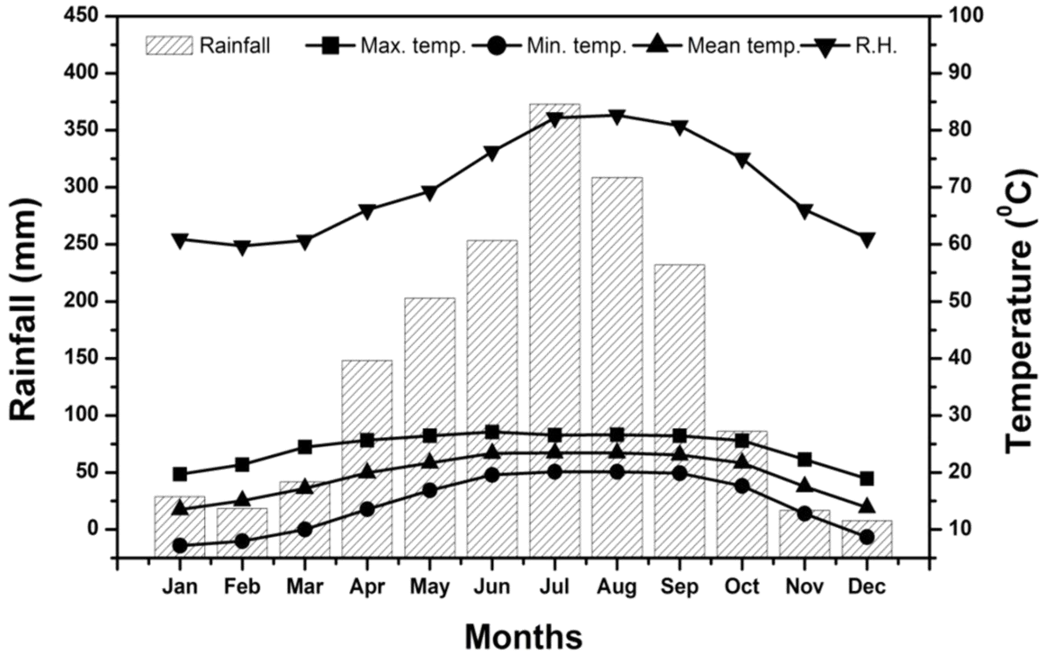


Fig.1: **Ombrothermic diagram based on ten years (2006-2016).**

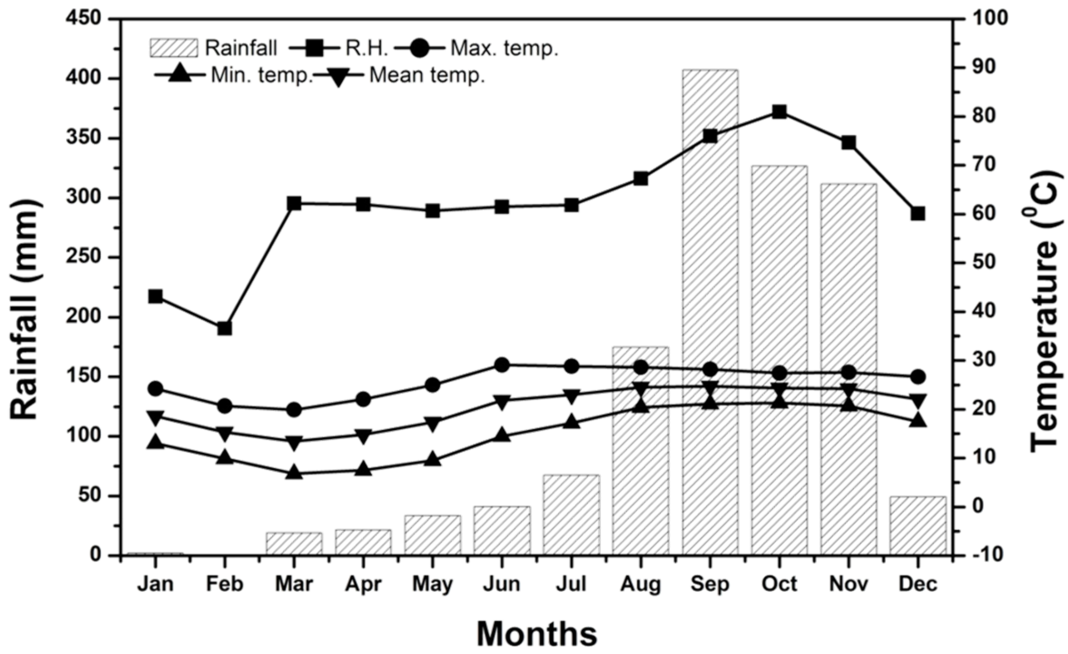


Fig.2: Climatic variation during the sampling period (2013-14).

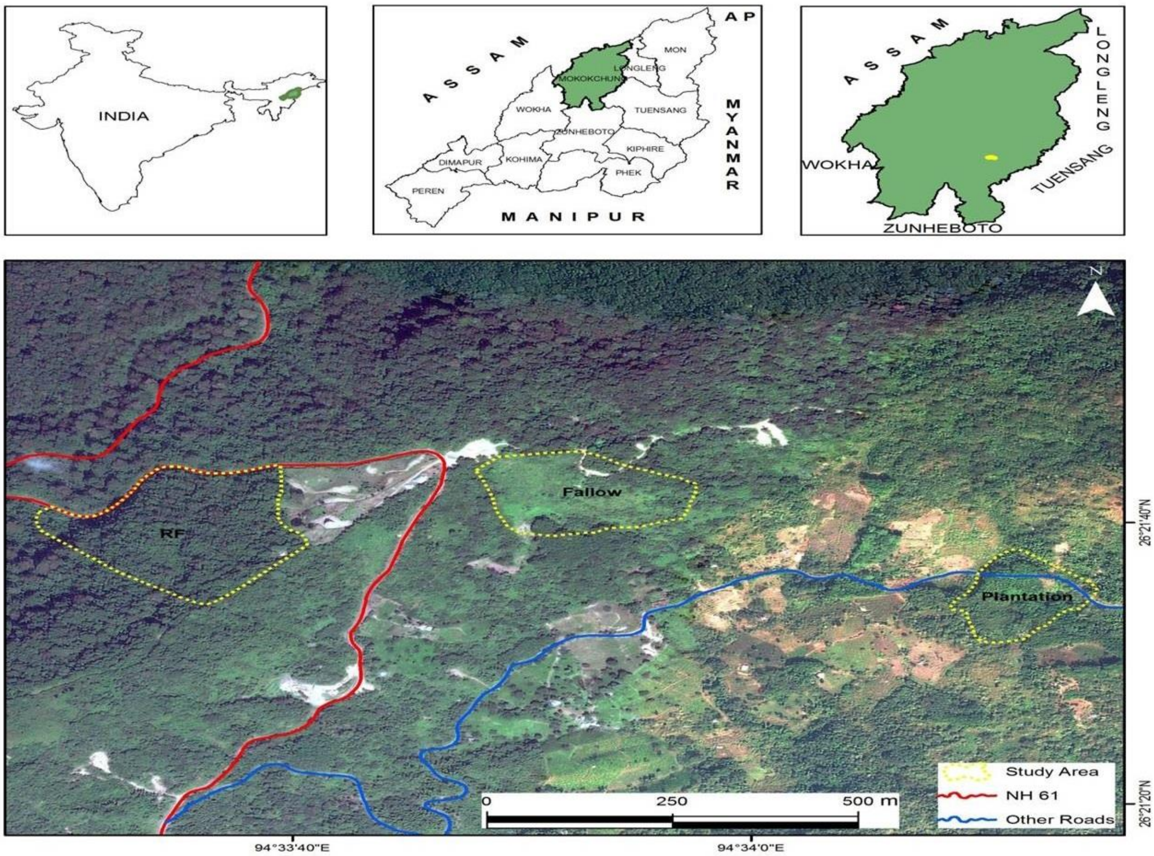


Plate 1: GIS map of Nagaland and study sites (Nagaland GIS and Remote Sensing Centre, Planning and Coordination).

Plate 2 a: Reserve forest.

Plate 2 b: Plantation.

Plate 2 c: Fallow land.

Chapter-IV

MATERIALS AND METHODS

Earthworm sampling, extraction, identification

Earthworms were collected from each site i.e., reserve forest (site I), fallow area (site II) and plantation (site III) which are further divided into upper, middle and lower strata according to the elevation having sloping landscape. In each elevation stratum, three plots having a size of 10x10m were selected with at least 40 m distance in between from where random sampling was done. The sampling period started from November 2013-October 2014. Three 25 x 25 x 30 cm monoliths were dug from each plot at regular monthly interval between 6.00 A.M.-10.00 A.M. Samples were collected up to a depth of 30cm and divided into three equal layers namely, 0-10cm, 10-20cm and 20-30cm in all sampling plots. The worms were then hand sorted following the tropical soil biology methodology (Anderson and Ingram, 1993). Since no worms were encountered at the 20-30 cm soil layer, the data up to 20 cm only was utilized for results and further analysis. The worms were brought to the laboratory, washed, weighed and straightened which were then preserved in 4% formalin for further taxonomic identification **(Plate 3-6).**

Soil analysis

Soil samples were collected at 0-10cm and 10-20 cm soil layers from nearby sampling plot of earthworm, packed in individual polythene bags to avoid moisture loss, labeled and immediately brought to laboratory **(Plate 7-8).** In laboratory soil samples were air-dried, powdered and subjected to further following analysis:

a) **Soil temperature**: Soil temperature was recorded every month at 0-10 and 10-20 cm soil layers using soil thermometer

b) **Soil moisture**: Soil moisture content was determined by gravimetric method (Mishra, 1968; Wilde *et al*., 1985) at 105 ºC. Soil samples were taken from two soil layers 0-10 and 10-20 cm on each sampling. Values were then converted to percentages.

c) **Bulk density**: Bulk density was also determined by gravimetric method (Allen *et. al.*, 1974)

d) **Soil pH**: Soil pH was measured by electrometric digital pH meter (Anderson and Ingram, 1993)

e) **Organic Carbon**: Organic carbon was determined by rapid titration method (Walkey and Black, 1934).

f) **Available nitrogen**: Available nitrogen was calculated following alkaline potassium permanganate method (Subbiah and Asija,1956)

g) **Available phosphorus**: Available phosphorus was determined spectrophoto-metrically (Anderson and Ingram, 1993).

h) **Potassium:** Potassium was also determined and measured by flame photometer (Ammonium Acetate Method of K Determination, Hanway and Heidel, 1952)

Statistical and community analysis

The statistical analysis such as standard error, correlation and ANOVA (single factor) were done using the SPSS version 17 and Microsoft excel.

In community analysis, species diversity and community similarity were analyzed for earthworm species using the following formulae.

Margalef's Index

Species diversity (number of species) or species richness was calculated after Margalef (1968).

$$Da = (S - 1)/ \log N$$

Where, *Da =Margalef's Index*

S = Number of species

N = Total number of individuals

Shannon-Wiener diversity index

Measure of species diversity based on information theory or related to the concept of 'Uncertainty' was calculated after Shannon and Wiener (1949).

$$H' = -\sum_{i=1}^{s} \text{Pi Log Pi}$$

Where, *H' = Measure of Shannon and Wiener diversity*

S = Total number of species in a sample

P_i = *Proportion of the total number of individuals occurring in species i.*

H max'

The maximum possible diversity of H' or H max' was calculated using the following formula

$$H\ max' = Log_2 S$$

Where, *S = Number of species or category*

Evenness

The evenness or equitability index (Pielou, 1969) of the individual, distribution among the species, designated by the quantity J' (also sometimes referred to as relative diversity) was calculated using the following formula.

$$J' = H / H\ max'$$

Where, *H' = Shannon-Weiner function or Mac-Arthur index of diversity (Mac. Arthur, 1955)*

Community similarity

The similarity or dissimilarities of the earthworm communities in the study sites were worked out using the following index:

The coefficient of similarity (CCs).of Sorenson (1948), also known as quotient of similarity (Q/S) was calculated using the following formula:

$$\frac{Q}{S} = \frac{2C}{S1+S2+S3} \times 100$$

Where, C= Number of species common to both the communities

S_1=Number of species in community 1 (Reserved forest Ecosystem)

S_2= Number of species in community 2 (Fallow Ecosystem)

S_3= Number of species in community 3 (Plantation Ecosystem)

Average faunal resemblance

The average faunal resemblance among three forest ecosystem was calculated using the following formula.

$$\text{Average faunal resemblance} = \frac{C(S_1+S_2+S_3)}{2\times S_1\times S_2\times S_3} \times 100$$

Where, C = Number of species common to both communities

S_1 = Total number of species in community 1 (Reserve forest)

S_2 = Total number of species in community 2 (Fallow land)

S_3 = Total number of species in community 3 (Plantation land)

Plate 3: Cleared site for earthworm extraction.

Plate 4: Digging of the quadrat.

Plate 5: Curled earthworms found during winter.

Plate 6: Bamboo container used for carrying live earthworms.

Plate 7: Collection of soil samples.

Plate 8: Soils collected in separate polythene bags.

Chapter-V

SOIL CHARACTERISTICS

The different physico-chemicals factors *viz.*, soil temperature, soil moisture, pH, bulk density, organic carbon, available nitrogen, phosphorus, and potassium were determined in the reserve forest, fallow and plantation ecosystems during the study period.

Soil temperature

The soil temperature of reserve forest, fallow and plantation ecosystem is represented in **(Figure 3 a, b and c)**. It has been observed that the soil temperature in the winter months is found to be minimum in the plantation ecosystem while in the fallow and the reserve forest ecosystem, it is a little higher with very minimal differences. Monthly variation of soil temperature followed the pattern of atmospheric temperature indicating the impact of atmospheric temperature on the soil. There was a slight decrease in the soil temperature with increase in soil depth; however, during winter months temperature was recorded to be slightly higher in lower depth than to soil layer. The low soil temperature in the reserve forest ecosystem could be due to the location, slope and the topography of the site with lesser exposure to sunlight. It has been observed that minimum and maximum soil temperature in both soil layers in all the three sites were recorded during January and September respectively.

In the reserve forest ecosystem, the soil temperature ranged from 10.10 ^{0}C to 23.63 ^{0}C in the 0-10 cm layer and from 10.73 ^{0}C to 23.83 ^{0}C in 10-20 cm layer. In the fallow ecosystem, it ranged from 15.32 ^{0}C to 25.20 ^{0}C in 0-10 cm layer and from 15.33 ^{0}C to 24.96 ^{0}C in 10-20 cm layer respectively.

While in the plantation ecosystem, the soil temperature ranged from 13.85 ^{0}C to 25.30 ^{0}C in the 0-10 cm layer and from 14.54 ^{0}C to 25.17 ^{0}C in 10-20 cm layer. In general, soil temperature indicated similar increasing pattern with a minimum during the winter and maximum during monsoon in the three sites.

Soil moisture content

The moisture content in the reserve forest ecosystem is recorded to be higher than in the fallow and plantation ecosystems **(Figure 4 a, b and c)**. The high moisture content in the reserve forest particularly during winter could be due to the good canopy which helps in the retention of water in the soil. Another possible reason could also be due to the disruptive activities like pruning, burning of litters and more exposure to sunlight in the fallow and plantation ecosystems as compared to the reserve forest.

In the reserve forest ecosystem, the minimum and maximum soil moisture content was recorded during March and September. It ranged from 34.82 % to 64.14 % in the 0-10 cm layer and from 26.29 % to 34.34 % in the 10-20 cm soil layer, indicating substantial moisture presence in the site.

In the fallow ecosystem, the soil moisture content ranged from 16.76 % (January) to 50.62 % (September) in the 0-10 cm layer and from 18.99 % (January) to 38.06 % (September) in the 10-20 cm layer.

In the plantation ecosystem, soil moisture content ranged from 24.37 % (January) to 56.42 % (September) in the 0-10 cm layer and from 19.98 % (January) to 39.96 % (August) in the 10-20 cm layer.

A higher percentage of soil moisture in the topsoil layer than in the 10-20 cm soil layer in all the study sites are in conformity with Huhta and Hanninen (2001) who also observed declining tendency of soil moisture content with the increase in soil depth.

Soil bulk density

The soil bulk density showed variation during each sampling months and the vertical analysis of bulk density exhibited an increasing trend with the increase in soil depth i.e. from 0-10 and 10-20 cm in all the study sites **(Figure 5 a, b and c).**

In the reserve forest ecosystem, the value ranged from 1.01 g cm^{-3} (September) to 1.24 g cm^{-3} (February) at 0-10 cm soil layer whereas in 10-20 cm soil layer the value ranged from 1.1 g cm^{-3} (July) to 1.26 g cm^{-3} (February).

In the fallow ecosystem, the value ranged from 1.03 g cm^{-3} (September) to 1.21 g cm^{-3} (February) at the 0-10 cm soil layer. In the 10-20 cm soil layer, the value ranged from 1.07 g cm^{-3} (July and October) to 1.28 g cm^{-3} (January and April).

The plantation ecosystem exhibited similar value ranges as in fallow ecosystem. The bulk density in the 0-10 cm soil layer ranged from 1.02 g cm^{-3} (September) to 1.23 g cm^{-3} (February) while in the 10-20 cm soil layer, the value ranged from 1.15 g cm^{-3} (November) to 1.29 g cm^{-3} (April).

The values in all the three sites indicated similar patterns with higher bulk density during the dry winter season than during wet monsoon season.

Soil pH

The soil pH showed acidic to slightly acidic in nature with the values ranging from 4.5 to 6.23 in the different soil layers in all the study sites **(Figure 6 a, b and c).** Soils of Nagaland are derivatives of tertiary rocks belonging to Barail and Disang series. Hence, they are generally acidic in nature, rich in organic carbon but poor in the availability of phosphate and potash content except in the valleys and in the foothills with comparatively level land and gentle gradients. Other possible reason for the acidic nature of the soil may be due to frequent and high rainfall especially during the monsoon season and also because of the type of soil.

The soil pH of forest ecosystem ranged from 4.53 (November) to 5.97 (August) at the 0-10 cm soil layer and at the 10-20 cm layer, the value varied from 4.5 (November) to 5.7 (December and March).

In the fallow ecosystem, the soil pH varied from 4.83 (November) to 6.23 (April) at 0-10 cm soil layer and 4.76 (November) to 6.23 (June) at 10-20 cm soil layer.

The plantation ecosystem exhibited soil pH values ranging from 5.1 (November) to 5.9 (April) at the 0-10 cm soil layer while the values ranged from 4.93 (November) to 5.63 (March) at the 10-20 cm layer. It is interesting to note that in all the study sites, the soil pH was more acidic in the month of November.

Available soil nitrogen (N)

The available soil nitrogen showed variations at different months in all the study sites **(Figure 7 a, b and c)** and exhibited higher and consistent concentration in the undisturbed forest ecosystem than in the plantation and fallow ecosystems.

In the forest ecosystem, the nitrogen value ranged from 204.77 kg/ha (August) to 352.77 kg/ha (July) at the 0-10 cm soil layer. At the 10-20 cm soil layer the value varied from 217.33 kg/ha (September) to 313.49 kg/ha (July).

In the fallow ecosystem, the nitrogen value interestingly showed the minimum in the month of September (196.43 kg/ha) and a maximum in the month of March (280.03 kg/ha) at the 0-10 cm soil layer. While in the 10-20 cm soil layer, the value ranged from 186.23 kg/ha (January) to 271.63 kg/ha (December).It is also interesting to note that the values remained more or less stable within the mentioned ranges throughout the year.

The plantation ecosystem also showed a similar trend as observed in the fallow ecosystem at the 0-10 cm soil layer with the value varying from 183.90 kg/ha (September) to 342.73 kg/ha (March). Even in the 10-20 cm soil layer, the value ranged from 146.27 kg/ha (September) to 271.63 kg/ha (March).

Available soil phosphorus (P)

The phosphorus also showed a fluctuation pattern in different months and soil depth in all the three study sites **(Figure 8 a, b and c).**

In the forest ecosystem, the value ranged from 8.20 kg/ha in December to 25.95 kg/ha in October and 7.63 kg/ha in December and 20.87 kg/ha in September at 0-10 cm and 10-20 cm soil layers respectively.

The phosphorus availability in fallow ecosystem varied from 9.37 kg/ha in December to 32.73 kg/ha in September at 0-10 cm and from 8.07 kg/ha in December to 27.66 kg/ha in September at 10-20 cm soil layer.

In the plantation ecosystem the value varied from 7.67 kg/ha in December to 26.35 kg/ha in September at 0-10 cm soil layer and from 7.93 kg/ha in January to 20.43 kg/ha in September at the 10-20 cm soil layer.

Soil potassium (K)

The soil potassium is represented in **(Figure 9 a, b and c).**

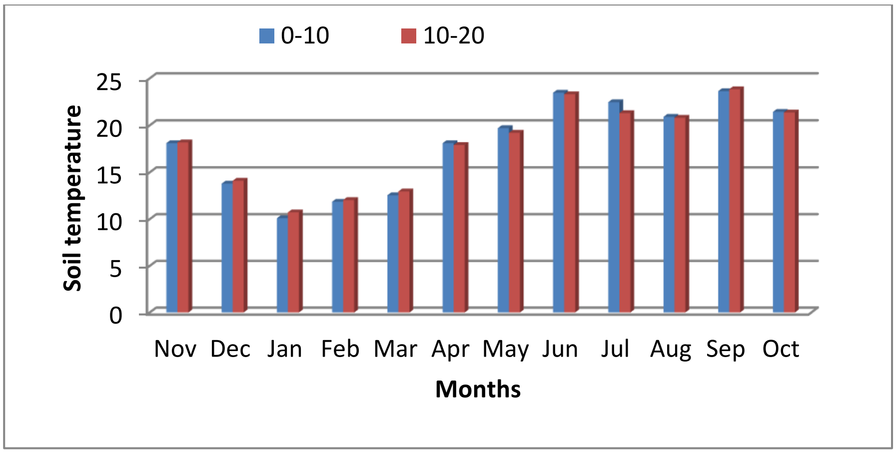
In the forest ecosystem, the value ranged from 63.67 kg/ha (April) to 179.38 kg/ha (May) at 0-10 and from 53.01 kg/ha (April) to 139.01 kg/ha (march) at 10-20 cm soil layers. In the fallow ecosystem the value ranged from 93.24 kg/ha (July) to 242.37 kg/ha (may) at 0-10 cm and 67.01 kg/ha (October) to 122.17 kg/ha (April) at 10-20 cm soil layer. While in the plantation ecosystem, the value varied from 79.61 kg/ha (September) to

163.37 kg/ha (April) at 0-10 cm and from 37.61 kg/ha (September) to 126.47 kg/ha (may) at 10-20 cm soil layers respectively.

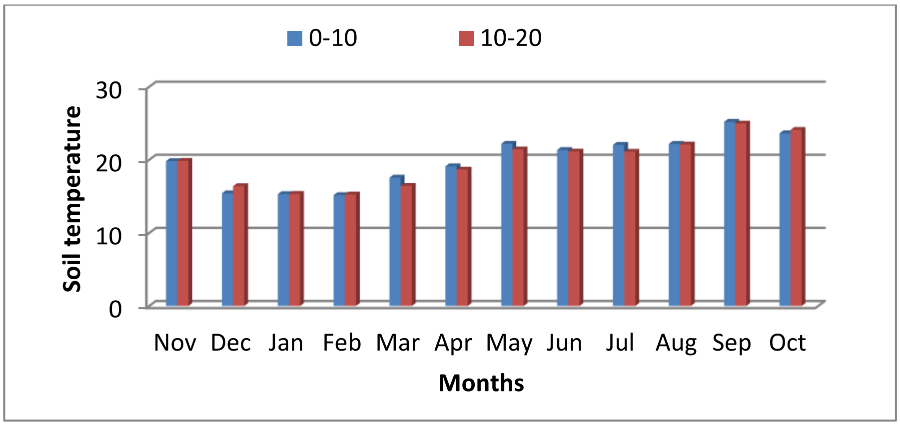
Soil organic carbon (C)

The soil organic carbon is comparatively more stable in the forest ecosystem than in the fallow and plantation ecosystem as represented in the **(Figure 10 a, b and c)**. In the forest ecosystem, the value ranged from 1.74 % (November) to 2.88 % (August) and from 1.22 % (November) to 2.06 % (March) at 10-20 cm soil layer. In the fallow ecosystem, the value ranged from 1.17 % (November) to 2.63 % (December) at 0-10 cm and from 0.93 % (November) to 2.40 % (March) at 10-20 cm respectively. While in the plantation ecosystem, the value ranged from 1.44 % (November) to 2.85 % (July) at 0-10 cm and from 0.87 % (November) to 2.47 % (May) at 10-20 cm layer.

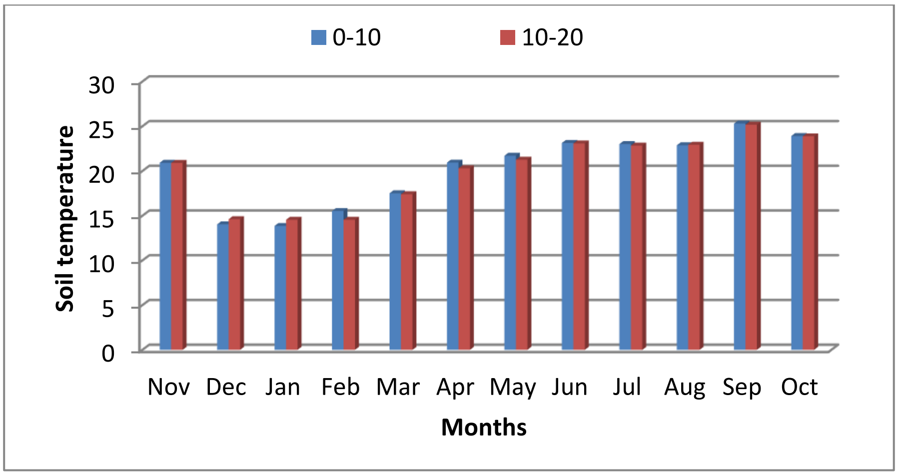
Consistency pattern of availability of soil organic matter and nitrogen in reserve forest than other two sites is due to higher accumulation of litter from diverse trees and a quicker rate of organic matter decomposition in the forest. A bare minimum of standing trees intermixed with grasses and monoculture of *Daubanga grandiflora* may be some reasons for the less accumulation and erratic fluctuation of organic and soil nitrogen content the fallow and plantation sites respectively. The decreasing trend of soil organic carbon and soil nitrogen with increasing depth from upper to lower layer in all the three study sites is in conformity with the findings of Martinucci (1979), Tsukamoto (1985), Singh and Dev (1995), Zhong *et al.* (2001) and Zhong and Qiquo (2001) from different ecosystems.



a) **Reserve forest ecosystem**

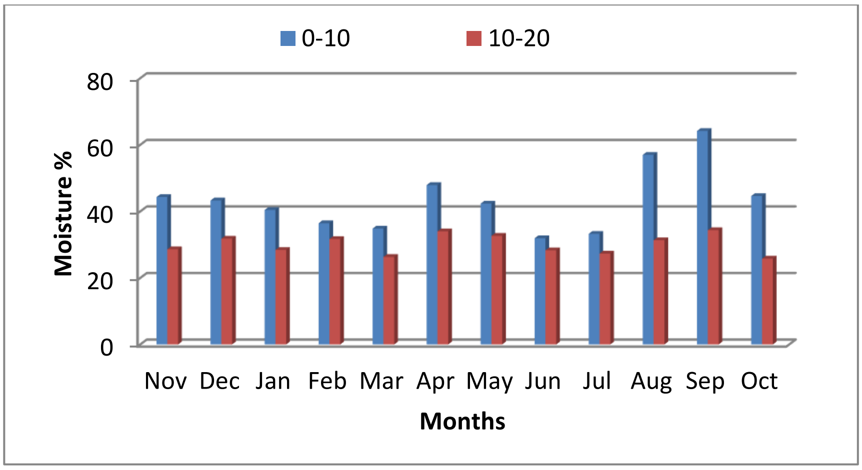


b) **Fallow land ecosystem**

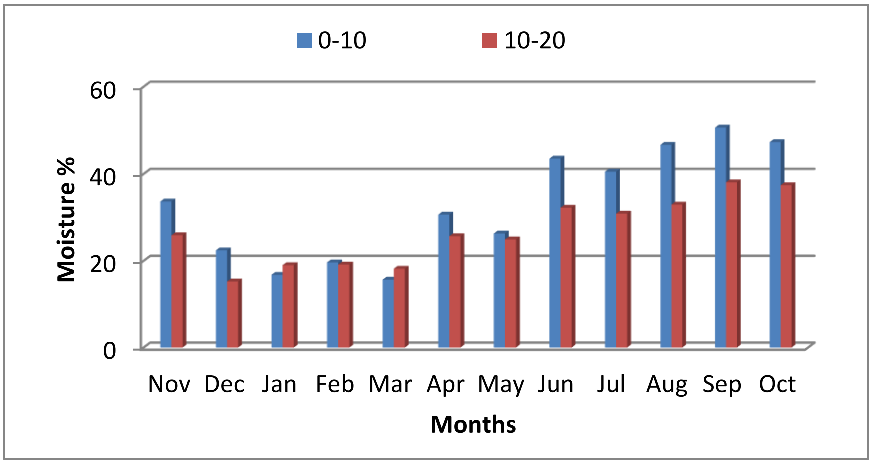


c) **Plantation ecosystem**

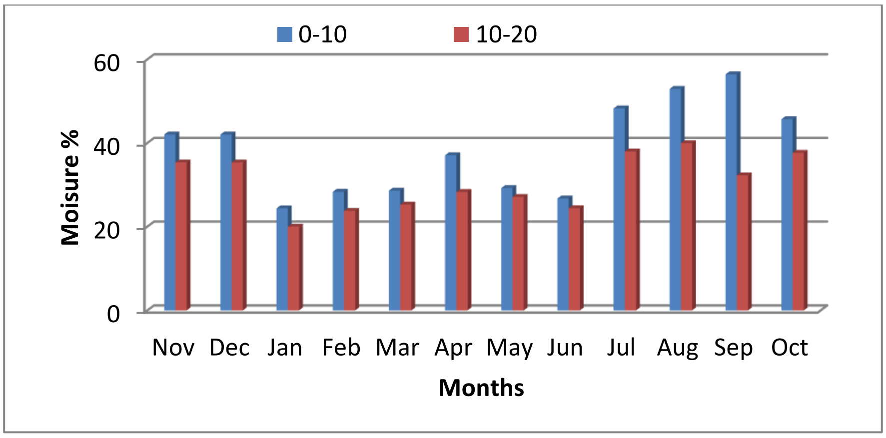
Figure 3: Monthly variation in soil temperature (^{0}C) at different soil layer (cm). (a) Reserve forest ecosystem (b) Fallow land ecosystem (c) Plantation ecosystem.



a) **Reserve forest ecosystem**

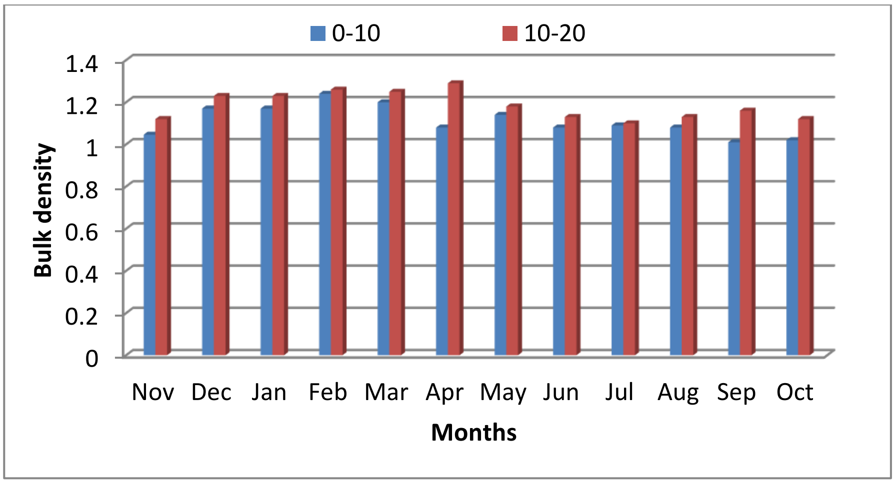


b) **Fallow land ecosystem**

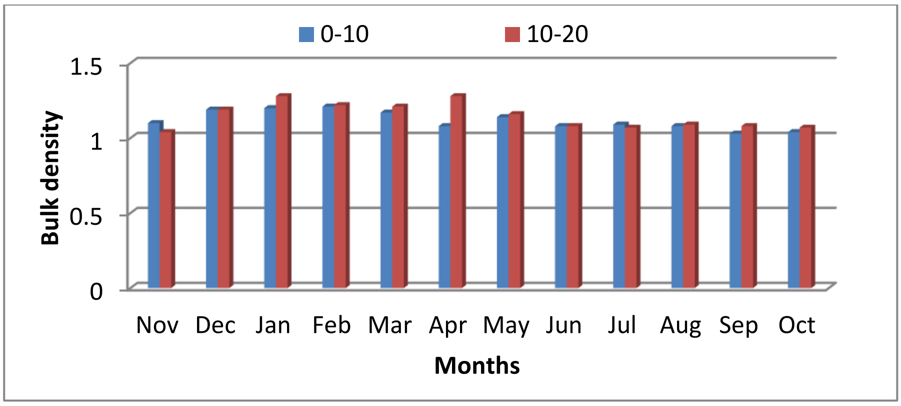


c) **Plantation ecosystem**

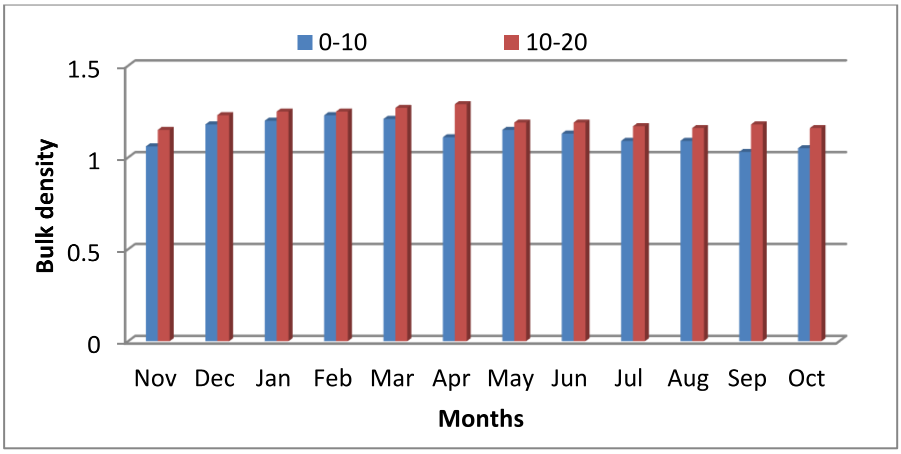
Figure 4: Monthly variation of moisture content (%) at different soil layers (cm). (a) Reserved forest ecosystem (b) Fallow land ecosystem (c) Plantation ecosystem.



a) **Reserve forest ecosystem**

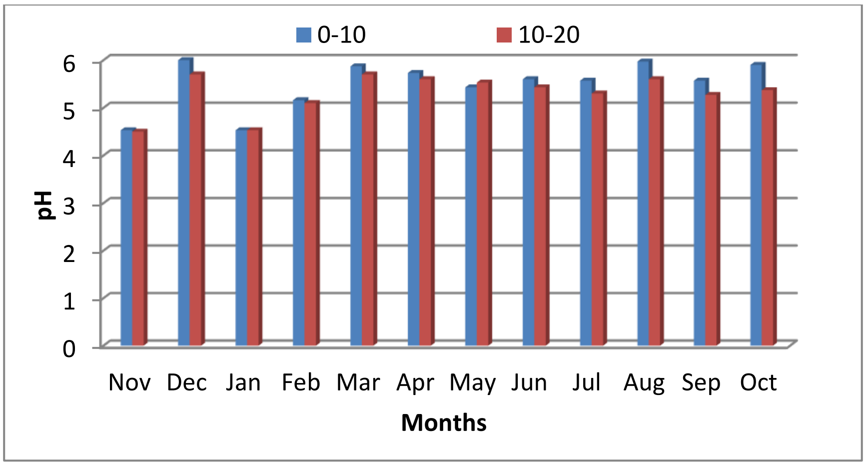


b) **Fallow land ecosystem**

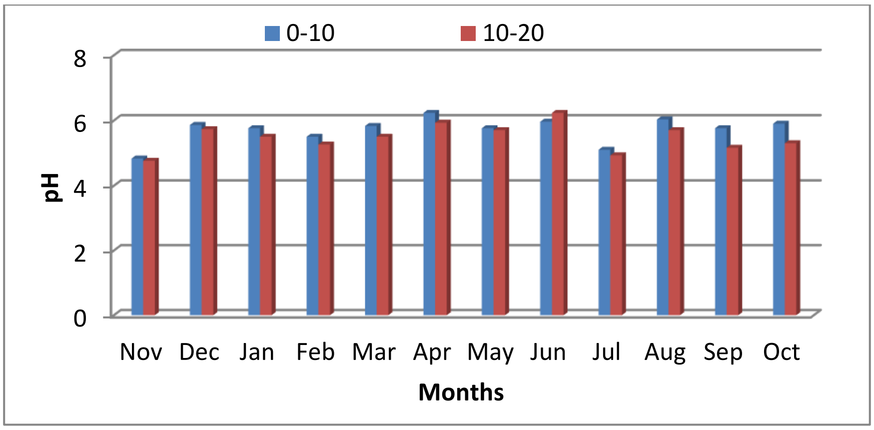


c) **Plantation ecosystem**

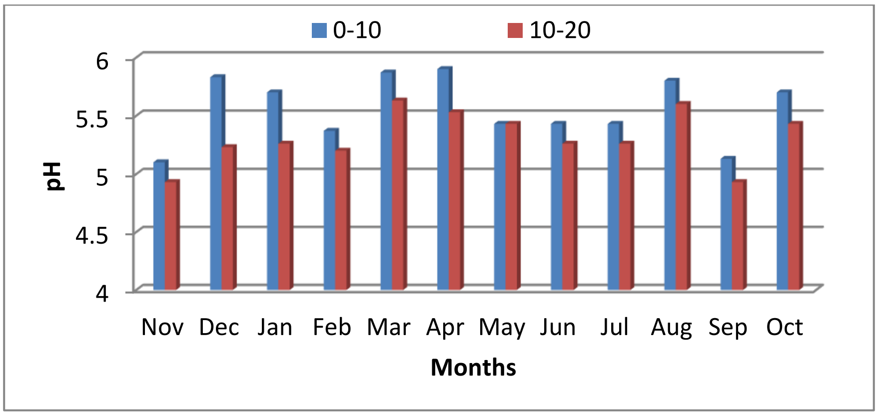
Figure 5: Monthly variation in bulk density (g cm^{-3}) at different soil layers (cm). (a) Reserve forest ecosystem (b) Fallow land ecosystem (c) Plantation ecosystem



a) **Reserve forest ecosystem**

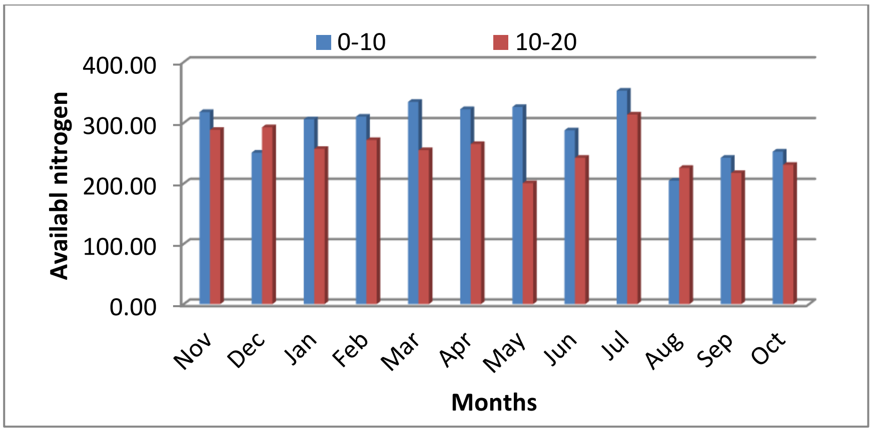


b) **Fallow land ecosystem**

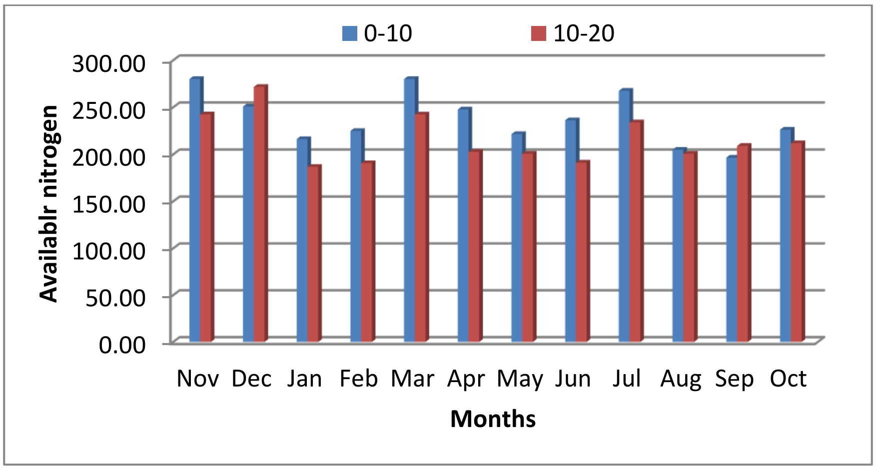


c) **Plantation ecosystem**

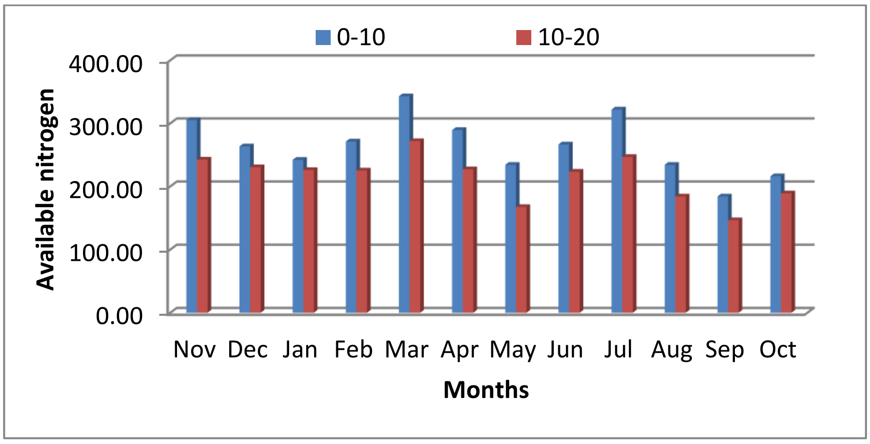
Figure 6: Monthly variation in Soil pH at different soil layers (cm). (a) Reserve forest ecosystem (b) Fallow land ecosystem (c) Plantation ecosystem.



a) **Reserve forest ecosystem**

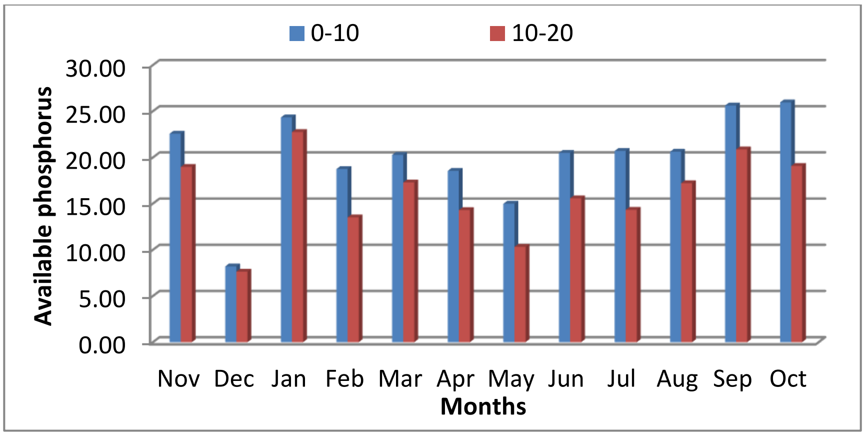


b) **Fallow land ecosystem**

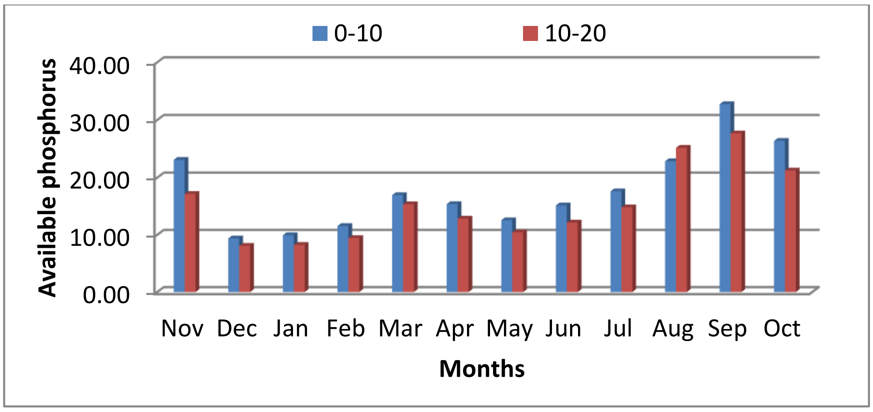


c) **Plantation ecosystem**

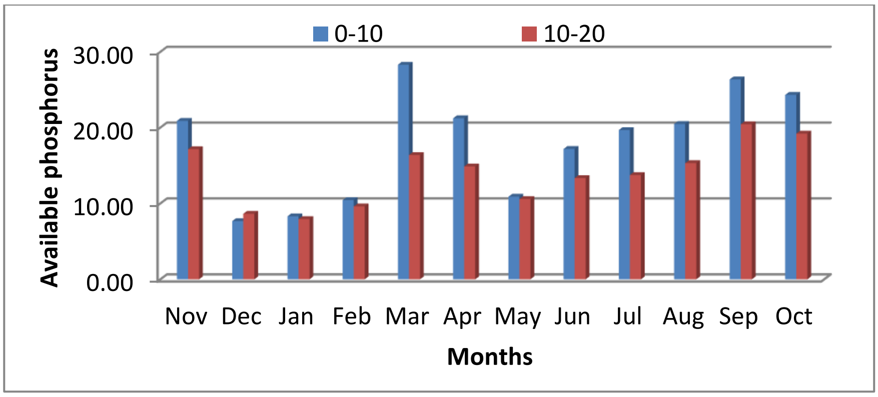
Figure 7: Monthly variation in the available Nitrogen (Kg/Ha) at different soil layers (cm). (a) Reserve forest ecosystem (b) Fallow land ecosystem (c) Plantation ecosystem.



a) **Reserve forest ecosystem**

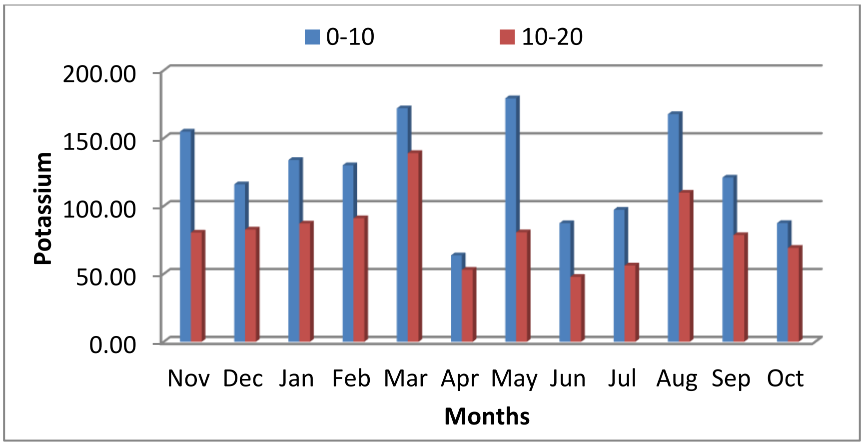


b) **Fallow land ecosystem**

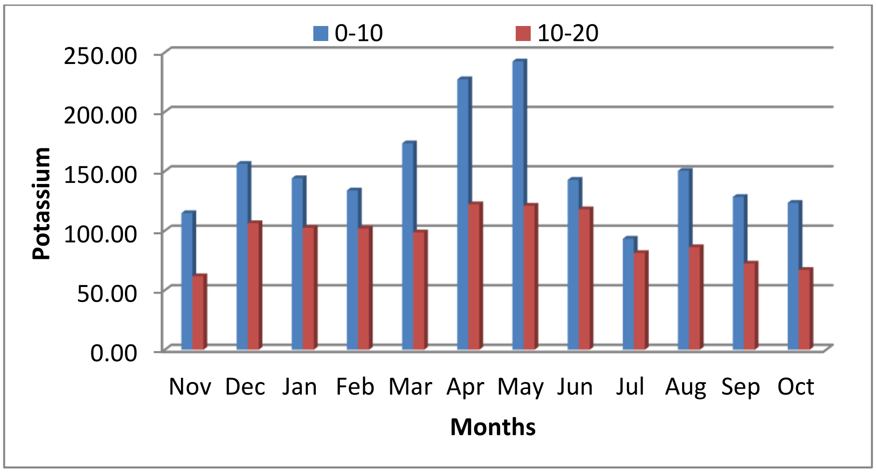


c) **Plantation ecosystem**

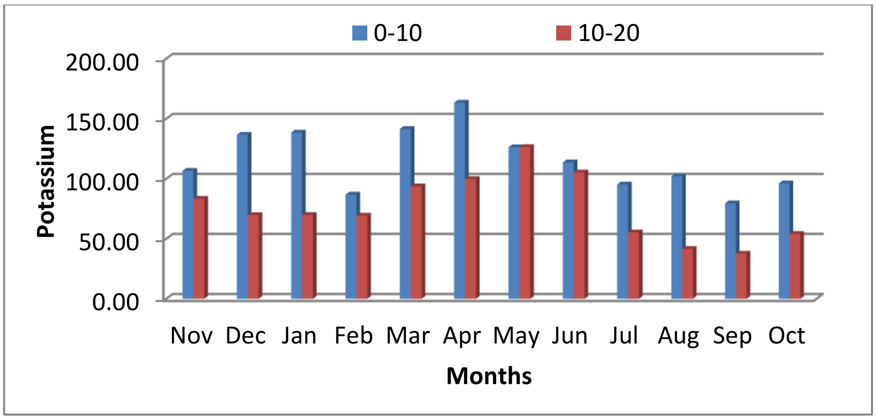
Figure 8: Monthly variation in the Phosphorus (Kg/Ha) at different soil layers (cm). (a) Reserve forest ecosystem (b) Fallow land ecosystem (c) Plantation ecosystem.



a) Reserve forest ecosystem

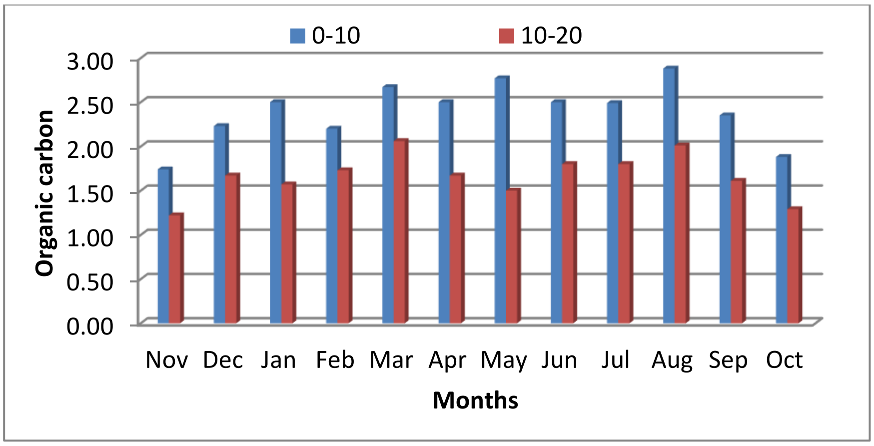


b) Fallow land ecosystem

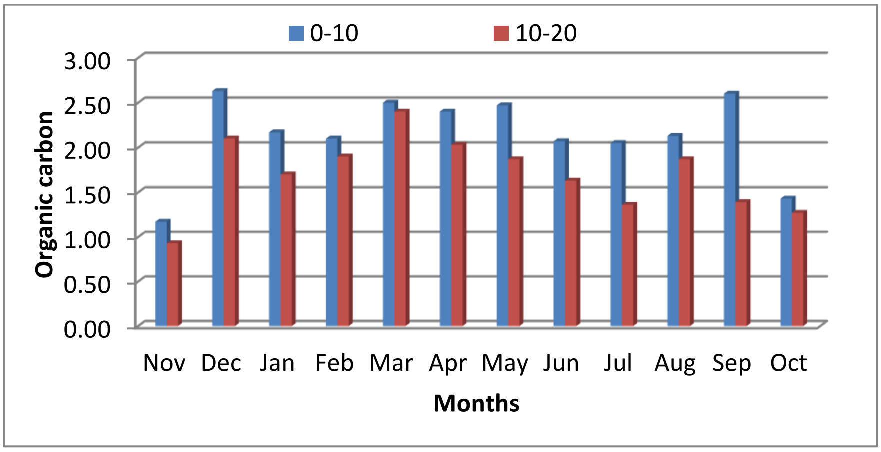


c) Plantation ecosystem

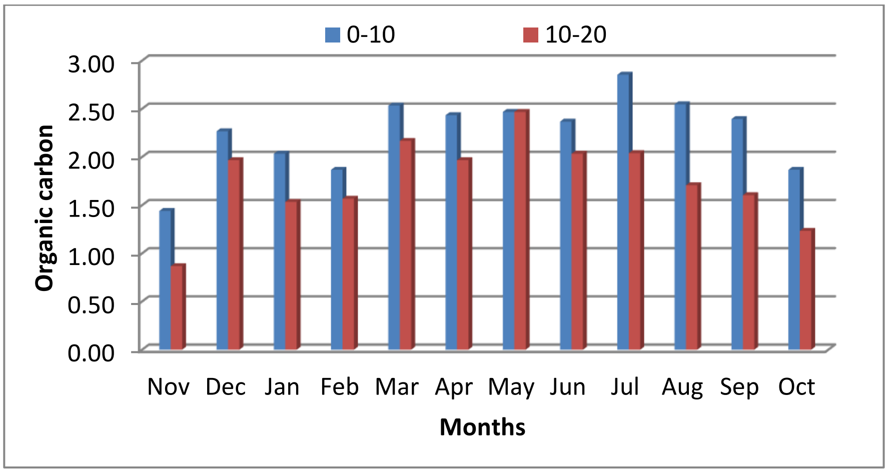
Figure 9: Monthly variation in the Potassium (Kg/Ha) at different soil layers (cm). (a) Reserve forest ecosystem (b) Fallow land ecosystem (c) Plantation ecosystem



a) **Reserve forest ecosystem**



b) **Fallow land ecosystem**



c) **Plantation ecosystem**

Figure 10: Monthly variation in the Organic Carbon (%) at different soil layers (cm). (a) Reserve forest ecosystem (b) Fallow land ecosystem (c) Plantation ecosystem.

Chapter-VI

POPULATION DYNAMICS AND BIOMASS OF EARTHWORMS

A total of seven species of earthworms belonging to three families *viz.*, Megascolecidae, Moniligastridae and Octochaetidae were recorded during the sampling period from the three study sites of reserve forest, fallow and plantation ecosystems. The three species of Megascolecidae included *Amynthas corticis*, *Amynthas* sp.1 and *Perionyx* sp., while Moniligastridae, was represented only by *Drawida* sp. and Octochaetidae was represented by *Eutyphoeus festivus*, *Eutyphoeus* sp. no.1 and *Eutyphoeus marmoreus* **(Plate 9-15).** Of the seven species, *Amynthas* sp.1 was collected only from the reserve forest ecosystem while all the other six species were found to be present in all the three sites. All the three ecological species categories viz. epigeic, endogeic and anecic (Bouchè, 1977) were represented in the present investigation. Out of the 7 species, 3 were epigeic species (*Amynthas corticis*, *Amynthas* sp.1 and *Perionyx* sp.), another 3 were endogeic (*Eutyphoeus festivus*, *Eutyphoeus* sp.no.1 and *Eutyphoeus marmoreus*) and only one species was anecic (*Drawida* sp.) of which *Eutyphoeus festivus* and *Drawida* were the two most abundant species of earthworm in all the three sites. Kale and Krishnamoorthy (1978) and Lavelle (1979) reported that sub-tropical ecosystems are generally dominated by endogeic species which was also in conformity to the present findings. *Eutyphoeus* earthworm species are endemic to Burma, eastern Himalaya and north-east ranges (Julka, 1988). *Drawida* belonging to the moniligastrid family is extensively present in the Indian peninsula, Eastern Himalaya, North-East ranges, Myanmar, East and Southeast Asia, China and Japan (Paliwal and Julka, 2005). Bhadauria and Ramakrishnan (1989, 1991)**,** Bhadauria *et al*. (2000) and Sinha *et al*. (2003) also reported the presence of *Drawida* which is endemic to the soils of India. Chaudhuri *et al*. (2009) also reported the exclusive presence of *Drawida* sp. and *Eutyphoeus* sp. in the rubber plantation of Tripura. Some species such as *Amynthas corticis, Drawida* sp. and *Eutyphoeus* sp. were also reported in the neighboring states of Manipur, Meghalaya, Tripura (Haokip and Singh, 2012; Mishra and Ramakrishanan, 1988; Chaudhari and Bhattarcharjee, 1999; Halder, 1999; Ramanujam *et al.,* 2004). Population dynamics and biomass of certain individual species on annual, seasonal and monthly variation are presented below:

Annual population density and biomass of *Perionyx* sp.

The total annual population density and their distribution pattern and biomass of *Perionyx* sp. in different soil layers showed higher aggregation at the topsoil layer in the reserve forest site followed by fallow and plantation sites respectively (**Table 1 a, b and c**). The higher concentration of population density in a natural forest may be attributed to vegetation cover and optimum physico-chemical factors, while monoculture and lack of canopy cover in other two sites may have had a negative impact on this species.

In the reserve forest, the total annual population density of *Perionyx* sp. recorded was 153.82 m^{-2}, which contributed to 25.06 % to the total earthworm population collected in both soil layers. It contributed to 27.02 % of total earthworms at 0-10 cm soil layer. Total biomass accumulation was 76.54 g m^{-2} contributing 13.91 % to the total biomass of all earthworms. Being an epigeic species, they prefer the topsoil layer for survival. The *Perionyx* sp. population was not found in the 10-20 cm soil layers throughout the sampling period.

In the fallow site, the total annual population density and biomass of *Perionyx* sp. recorded was 35.45 m^{-2} and 19.31 g m^{-2} contributing 9.93 % and 7.58% respectively to total earthworm population. Percentage contribution of density and biomass of this species at 0-10 cm layer was 10.24% and 7.89% respectively. The species was not recorded at 10-20 cm soil layer as in the case of natural forest area.

In the plantation site, the annual population density of *Perionyx* sp. recorded was 17.11 m^{-2}, contributing only 4.4 % to the total earthworm population in all soil layers. With an increase in soil depth, *Perionyx* sp. showed decreasing trend i.e.15.86 m^{-2} (92.69 %) at 0-10 cm and 1.22 m^{-2} (7.13 %) at 10-20 cm. It contributed 4.35 % and 4.99 % to the total earthworms at 0-10 and 10-20 cm soil layers respectively. While overall biomass of this species was 3.74 gm^{-2} (1.72%), the strata wise accumulation of species was 3.52 g m^{-2} (1.76%) and .23 g m^{-2} (1.28%) at 0-10 and 10-20 cm soil layer respectively.

Table 1: Annual total number and biomass of *Perionyx* sp. in different sites.

(A=percentage contribution to the same species among the soil layers i.e. 0-10 and 10-20 cm)

(B=percentage contributions to the total earthworms in each soil layer respectively)

Density= (Numbers ± S.E. m^{-2}); Biomass= g m^{-2}

Soil layer (cm)	Density	Biomass	A		B	
	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	153±1.85	76.54±0.93	100	100	27.02	15.97
10-20	0	0	0	0	0	0
Annual	153.82±1.85	76.54±0.93	100	100	25.06	13.91

a) **Reserve forest ecosystem**

Soil layer (cm)	Density	Biomass	A		B	
	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	35.45±0.81	19.31±0.49	100	100	10.24	7.89
10-20	0	0	0	0	0	0
Annual	35.45±0.81	19.31±0.49	100	100	9.93	7.58

b) **Fallow land ecosystem**

Soil layer (cm)	Density	Biomass	A		B	
	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	15.86±0.35	3.51±0.06	92.69	93.85	4.35	1.76
10-20	1.22±0.10	0.23±0.01	7.13	6.14	4.99	1.28
Annual	17.11±0.45	3.74±0.07	100	100	4.4	1.72

c) **Plantation ecosystem**

Seasonal variation of density and biomass of *Perionyx* sp.

The seasonal variations in density and biomass of *Perionyx* sp. in the reserve forest, plantation and fallow sites are shown in **Table 2 a, b and c**.

In the reserve forest ecosystem, the population density of *Perionyx* sp. was more during the monsoon season (70.73 m^{-2}) followed by winter (42.77 m^{-2}) and pre-monsoon (40.33 m^{-2}) respectively. Similarly, maximum biomass was recorded in the monsoon season (29.04 g m^{-2}) followed by winter (27.80 g m^{-2}) and pre-monsoon (19.68 g m^{-2}) respectively. No *Perionyx* sp. Individuals were found in the 10-20 cm soil layers in any of the seasons.

In the fallow ecosystem, the population density of *Perionyx* sp. was recorded highest during monsoon season (20.77 m^{-2}), followed by pre-monsoon season (11.01 m^{-2}) and winter season (3.66 m^{-2}) respectively. Maximum biomass of *Perionyx* sp. was also recorded in the monsoon season with 8.76 g m^{-2} followed by pre-monsoon with 7.97 g m^{-2} and winter with 2.57 g m^{-2}.

In plantation ecosystem, *Perionyx* sp. population was recorded in both soil layers during the winter season, however, it was absent in 10-20cm soil layer in monsoon and pre-monsoon seasons. The density of *Perionyx* sp. was maximum during the winter season (7.33 m^{-2}), followed by monsoon season (6.11 m^{-2}) and pre-monsoon (3.67 m^{-2}). Winter (1.80 g m^{-2}) recorded the maximum biomass followed by monsoon (1.02 g m^{-2}) and pre-monsoon (.91 g m^{-2}) at 0-20 cm soil layer. The presence of earthworm in deeper layers (10-20 cm) during winter (1.22 ind. m^{-2} and 0.23 g m^{-2}) in plantation area may be due to less vegetation cover with comparatively drier condition facilitating the earthworm to burrow deep into the soil.

Table 2: Seasonal variation in density (Nos. m^{-2}) and biomass (gm^{-2}) of *Perionyx* sp. in different sites.

Season	soil layers (cm)				Total	
	0-10		10-20			
	Density	Biomass	Density	Biomass	Density	Biomass
Winter	42.77±1.75	27.80±1.74	0	0	42.77±1.75	27.80±1.74
Pre-monsoon	40.33±.3.39	19.68±1.72	0	0	40.33±.3.39	19.68±1.72
Monsoon	70.73±3.35	29.04±1.58	0	0	70.73±3.35	29.04±1.58
Annual	153±1.85	76.54±0.93	0	0	153.82±1.85	76.54±0.93

a) Reserve forest ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20			
	Density	Biomass	Density	Biomass	Density	Biomass
Winter	3.66±0.30	2.57±0.33	0	0	3.66±0.30	2.57±0.33
Pre-monsoon	11.01±1.53	7.97±0.97	0	0	11.01±1.53	7.97±0.97
Monsoon	20.77±1.89	8.76±1.09	0	0	20.77±1.89	8.76±1.09
Annual	35.45±0.81	19.31±0.49	0	0	35.45±0.81	19.31±0.49

b) Fallow land ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20			
	Density	Biomass	Density	Biomass	Density	Biomass
Winter	6.11±0.58	1.57±0.14	1.22±0.30	0.23±0.01	7.33±0.88	1.80±0.15
Pre-monsoon	3.67±0.58	0.91±0.13	0	0	3.67±0.58	0.91±0.13
Monsoon	6.11±0.76	1.02±0.08	0	0	6.11±0.76	1.02±0.08
Annual	15.89±0.45	3.51±0.06	1.22±0.30	0.23±0.01	17.11±0.45	3.74±0.07

c) Plantation ecosystem

Monthly variation of *Perionyx* sp.

Monthly variations of *Perionyx* sp. population density and biomass did not show any consistency in the different sites **(Figure 11 a and b).**

In the natural forest, maximum density was recorded in the months of September and October (23.22 m^{-2}) while no species was recorded in the month of June. No worm was encountered in the 10-20 cm soil layers in any month of the sampling period. With great variations, biomass showed three peaks during February (11.19 g m^{-2}), August (9.71 g m^{-2}) and October (9.62 g m^{-2}).

In fallow site, population density showed one peak month during October (8.55 m^{-2}). No species were found in the 10-20 cm soil layer. While a minimum density of 1.22 m^{-2} was recorded during the months of November, December and February, no earthworm was encountered in January and August. With the steady increase, biomass accumulation exhibited two peaks during June (4.72 g m^{-2}) and still higher during September (5.22 g m^{-2})

In the plantation site also, two peak periods of density were observed in December and October (3.66 m^{-2}) respectively. Further, 1.22 m^{-2} number of this species was recorded at 10-20 cm soil layer during the month of December. No *Perionyx* sp. population was recorded in February, April, June and August. Biomass was very low in this site with maximum accumulation during December (0.72 g m^{-2}).

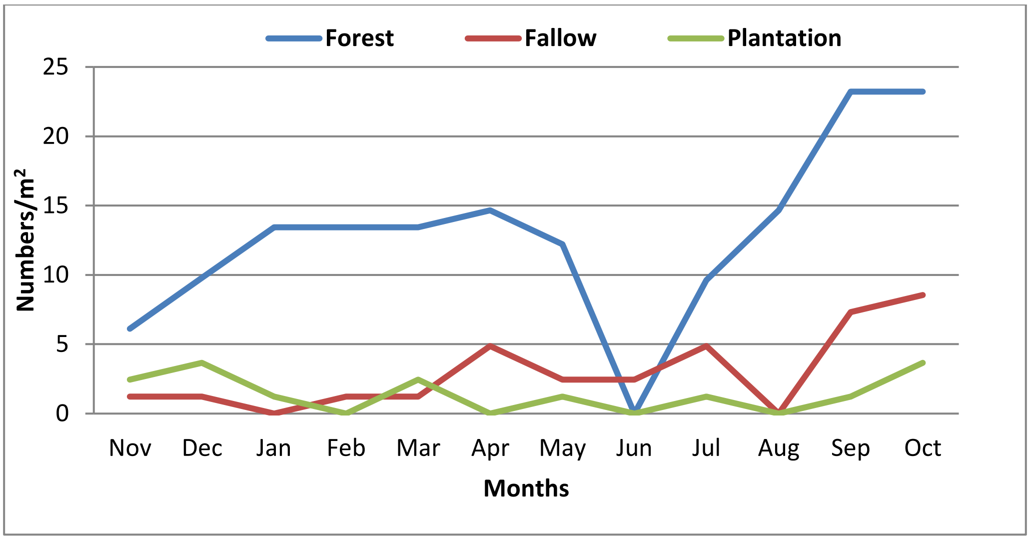


Figure 11 (a): **Monthly variation of population density of *Perionyx* sp. in different sites (Nos. m^{-2}).**

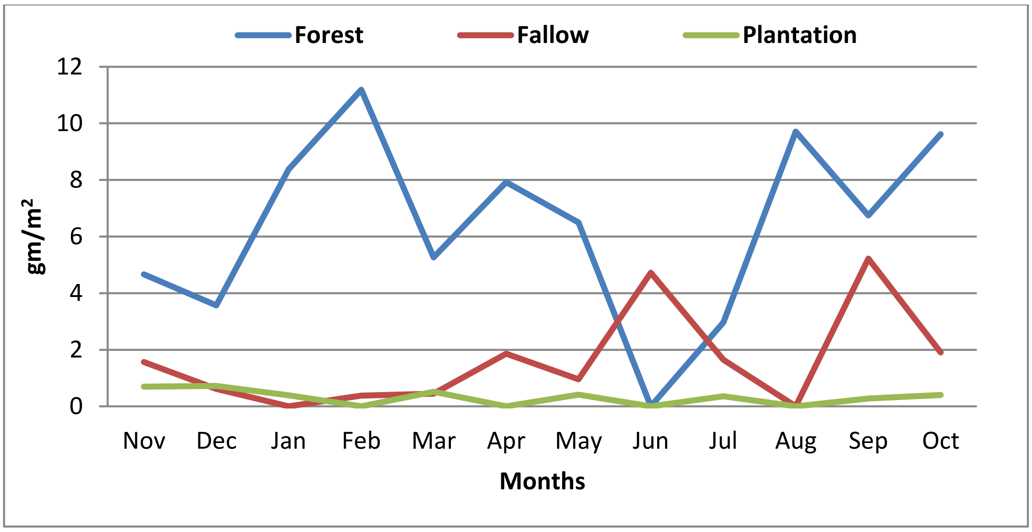


Figure 11 (b): **Monthly variation of biomass of *Perionyx* sp. in different sites (g m^{-2}).**

ANOVA for population density

The ANOVA for *Perionyx* sp. representing epigeic category was done which indicated variation in the population density in different seasons in all three the study sites.

Analysis of variance (ANOVA) of *Perionyx* sp. population in the forest ecosystem showed significant variation between the months of monsoon (F= 11.32, P > 0.05) and annual (F= 2.58, P < 0.05) at 0-10 cm soil layer **(Table 3).** There was no significant variation between the months of pre-monsoon season (F= 0.33, P > 0.05) at 0-10 cm layer.

ANOVA of *Perionyx* sp. population in fallow ecosystem showed significant difference between the months of annual (F= 3.94, P < 0.05) at 0-10 cm soil layer but it did not show any significant variation between the months of pre-monsoon (F= 0.43, P > 0.05 and monsoon (F= 0.36, P > 0.05) in the same layer **(Table 4).** Analysis of variance (ANOVA) of *Perionyx* sp. density in plantation area showed significant differences between the months of monsoon (F= 20.34, P < 0.05) and annual (F= 4.09, P < 0.05) at 0-10cm soil layer **(Table 5).** There was no significant variation between the months of winter (F= 1.30, P > 0.05) and pre-monsoon (F= 0.77, P < 0.05).

Table 3: Analysis of variance (ANOVA) of *Perionyx* sp. in the forest ecosystem (site-I) at 0-10 cm soil layer.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	11	254.32	23.12	**	**
		Within the months	0	0.00			
		Total	11	254.32			
	Pre-monsoon	Between the months	4	203.43	50.85	0.33	> 0.05
		Within the months	7	1061.76	151.68		
		Total	11	1265.19			
	Monsoon	Between the months	8	32161.11	407.63	11.32	< 0.05
		Within the months	3	107.94	35.98		
		Total	11	3369.06			
	Annual	Between the months	20	2008.71	100.43	2.58	< 0.05
		Within the months	14	581.74	38.78		
		Total	35	2590.45			

**: ANOVA showed no result.

Table 4: Analysis of variance (ANOVA) of *Perionyx* sp. in the fallow land ecosystem (Site-II) at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	10	30.14	3.01	**	**
		Within the months	1	0.00	0.00		
		Total	11	30.14			
	Pre-monsoon	Between the months	7	48.12	6.87	0.43	> 0.05
		Within the months	4	62.65	15.66		
		Total	11	110.78			
	Monsoon	Between the months	6	95.13	3.35	0.36	> 0.05
		Within the months	5	239.67	9.35		
		Total	11	334.80			
	Annual	Between the months	15	1185.36	79.02	3.94	< 0.05
		Within the months	20	400.80	20.04		
		Total	35	1586.17			
10-20	Winter	Between the months	8	NA	NA	**	**
		Within the months	3	NA	NA		
		Total	11	NA			
	Pre-monsoon	Between the months	8	13.39	0.76	0.23	> 0.05
		Within the months	3	8.93	0.33		
		Total	11	22.32			
	Monsoon	Between the months	4	NA	NA	**	**
		Within the months	7	NA	NA		
		Total	11	NA			
	Annual	Between the months	14	15.25	1.09	2.27	< 0.05
		Within the months	21	10.04	0.47		
		Total	35	25.30			

NA: ANOVA not computed since no earthworm was recorded.

**: ANOVA showed no result.

Table 5: Analysis of variance (ANOVA) of *Perionyx* sp. in the plantation ecosystem (Site-III) at 0-10 soil layer.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	10	87.29	8.72	1.30	> 0.05
		Within the months	1	6.69	6.69		
		Total	11	93.98			
	Pre-monsoon	Between the months	9	23.44	2.60	0.77	> 0.05
		Within the months	2	6.69	3.34		
		Total	11	30.14			
	Monsoon	Between the months	9	613.12	68.12	20.34	< 0.05
		Within the months	2	6.69	3.34		
		Total	11	619.82			
	Annual	Between the months	28	329.08	11.75	4.09	< 0.05
		Within the months	7	20.09	2.87		
		Total	35	349.18			

ANOVA for Biomass

In the reserve forest ecosystem the ANOVA of *Perionyx* sp. biomass showed significant differences between the months of monsoon (F= 4.66, P < 0.05) and annual (F= 2.98, P < 0.05) at 0-10 cm but showed no significant variation between the months of winter (F= 6.50, P > 0.05) and pre-monsoon (F= 0.29, P > 0.05) in the same layer (**Table 6**).

ANOVA of *Perionyx* sp. biomass in the fallow land showed significant differences between the months of winter (F= 26.31, P < 0.05), pre-monsoon (F= 10.74, P < 0.05), monsoon (F= 10.74, P < 0.05) and annual (F= 11.34 P < 0.05) at 0-10 cm layer. However, at 10-20 cm layer, no significant difference was exhibited between the months of pre-monsoon (F= 0.90.P > 0.05) and annual (F= 0.28, P > 0.05) (**Table 7**).

In the plantation ecosystem, ANOVA of *Perionyx* sp. biomass showed significant differences between the months of monsoon (F= 0.70, P < 0.05) and annual (F= 7.03, P < 0.01), but it did not show any significant variation between the months of pre-monsoon (F= 6.46, P > 0.05) at 0-10 cm soil (**Table 8**). At the 10-20 cm soil layer, it did not exhibit significant differences between the months of winter (F= 0.31, P > 0.05) and annual (F= 0.44, P > 0.05).

Table 6: Analysis of variance (ANOVA) of biomass of *Perionyx sp*. in the forest ecosystem (Site-I) at 0-10 cm soil layer.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	10	164.54	16.45	6.50	> 0.05
		Within the months	1	2.53	2.53		
		Total	11	167.07			
	Pre-monsoon	Between the months	7	124.02	17.71	0.29	> 0.05
		Within the months	4	237.58	59.39		
		Total	11	361.61			
	Monsoon	Between the months	6	367.05	61.17	4.66	< 0.05
		Within the months	5	65.60	13.12		
		Total	11	332.66			
	Annual	Between the months	17	441.71	25.98	2.98	< 0.05
		Within the months	18	156.64	8.70		
		Total	35	598.35			

Table 7: Analysis of variance (ANOVA) of biomass of *Perionyx sp.* in the fallow land (Site-II) ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	7	119.38	17.05	26.31	< 0.05
		Within the months	4	2.59	0.64		
		Total	11	121.97			
	Pre-monsoon	Between the months	6	165.19	27.56	10.74	< 0.05
		Within the months	5	12.80	2.56		
		Total	11	178.00			
	Monsoon	Between the months	6	165.19	27.56	10.74	< 0.05
		Within the months	5	12.80	2.56		
		Total	11	178.00			
	Annual	Between the months	21	364.07	17.33	11.34	< 0.01
		Within the months	4	21.39	1.52		
		Total	35	385.47			
10-20	Winter	Between the months	8	NA	NA	*	**
		Within the months	3	NA	NA		
		Total	11	NA			
	Pre-monsoon	Between the months	7	0.47	0.06	0.90	> 0.05
		Within the months	4	0.29	0.07		
		Total	11	0.77			
	Monsoon	Between the months	10	NA	NA	*	**
		Within the months	1	NA	NA		
		Total	11	NA			
	Annual	Between the months	21	0.26	0.01	0.28	> 0.05
		Within the months	14	0.61	0.04		
		Total	35	0.87			

NA: ANOVA not computed since no earthworm was recorded.

**: ANOVA showed no result.

Table 8: Analysis of variance (ANOVA) of biomass of *Perionyx sp*. in the plantation ecosystem (Site-III) at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	8	4.90	0.61	**	**
		Within the months	3	0.00	0.00		
		Total	11	4.90			
	Pre-monsoon	Between the months	7	11.04	1.57	6.46	< 0.05
		Within the months	4	.97	0.24		
		Total	11	12.02			
	Monsoon	Between the months	6	1.10	0.18	0.70	> 0.05
		Within the months	5	1.30	0.26		
		Total	11	2.41			
	Annual	Between the months	15	33.23	2.21	7.03	< 0.01
		Within the months	20	6.29	0.31		
		Total	35	39.52			
10-20	Winter	Between the months	8	0.19	0.02	0.31	> 0.05
		Within the months	3	0.23	0.07		
		Total	11	0.43			
	Pre-monsoon	Between the months	9	NA	NA	**	**
		Within the months	2	NA	NA		
		Total	11	NA			
	Monsoon	Between the months	8	NA	NA	**	**
		Within the months	3	NA	NA		
		Total	11	NA			
	Annual	Between the months	14	0.10	0.00	0.44	> 0.05
		Within the months	21	0.35	0.01		
		Total	35	0.46			

NA: ANOVA not computed since no earthworm was recorded.

**: ANOVA showed no result.

Annual population density and biomass of *Eutyphoeus festivus*

The total annual population density and total biomass of *Eutyphoeus festivus* and their distribution pattern in different soil layers showed that density was maximum in the plantation site (182.22 m^{-2}) followed by the reserve forest site (173.55 m^{-2}) and fallow site (119.77 m^{-2}) while the total annual biomass in the different soil layers was maximum in reserve forest site (161.46 g m^{-2}) followed by plantation site (109.70 g m^{-2}) and fallow site (86.83 g m^{-2}) (**Table 9 a, b and c).**

In the reserve forest ecosystem, total annual population density and biomass was 173.55 m^{-2} (28.27 %) and 161.46 g m^{-2} (29.36%) respectively. Density and biomass showed decreasing trend with increasing depth i.e. 157.67 m^{-2} (90.94%) and 138.41 g m^{-2} (85.72%) respectively at 0-10 cm and 15.89 m^{-2} (9.15%) and 23.05 g m^{-2} (14.27%) at 10-20 cm soil layer. Percentage contribution of density and biomass of this species to total earthworm population is reflected as 27.85% and 28.88% at 0-10 cm and 33.02% and 20.2% at 10-20 cm soil layer respectively.

In the fallow site, total annual population density and biomass was 119.77 m^{-2} (33.55 %) and 86.83 g m^{-2} (34.1%) respectively. Density and biomass also showed decreasing trend with increasing depth i.e. 116.11m^{-2} (96.94%) and 79.08g m^{-2} (91.07%) respectively at 0-10 cm and 3.66 m^{-2} (3.05%) and 7.75 g m^{-2} (8.92%) at 10-20 cm soil layer. Percentage contribution of density and biomass of this species to total earthworm population is reflected as 33.55% and 32.31% at 0-10 cm and 33.33% and 78.52% at 10-20 cm soil layer respectively.

In the plantation site, the annual population density and biomass of *Eutyphoeus festivus* was 182.22 m^{-2}, contributing 46.87 % and 109.70g m^{-2}, contributing 50.64 % respectively to the total earthworm population. With increase in soil depth, population

Table 9: Annual total number and biomass of *Eutyphoeus festivus* in different sites.

(A=percentage contribution to the same species among the soil layers i.e. 0-10 and 10-20 cm)

(B=percentage contributions to the total earthworms in each soil layer respectively)

Density= (Numbers ± S.E. m^{-2}); Biomass= g m^{-2}

Soil layer (cm)	Density	Biomass	A		B	
	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	157.667±1.26	138.41±2.64	90.84	85.72	27.85	28.88
10-20	15.89±0.87	23.05±1.25	9.15	14.27	33.34	20.2
Annual	173.55±2.13	161.46±3.89	100	100	28.27	29.36

a) Reserve forest ecosystem

Soil layer (cm)	Density	Biomass	A		B	
	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	116.11±1.38	79.08±1.49	96.94	91.07	33.55	32.31
10-20	3.66±0.15	7.75±0.59	3.05	8.92	33.33	78.52
Annual	119.77±1.53	86.83±2.08	100	100	33.55	34.1

b) Fallow land ecosystem

Soil layer (cm)	Density	Biomass	A		B	
	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	170±2.86	98.54±1.39	93.29	89.82	46.66	49.58
10-20	12.22±0.47	11.16±0.47	6.7	10.17	50.02	62.45
Annual	182.22±3.33	109.70±1.86	100	100	46.87	50.64

c) Plantation ecosystem

density showed decreasing trend i.e.170 m^{-2} (93.29 %) at 0-10 cm and 12.22 m^{-2} (6.7 %) at 10-20 cm. A similar trend was also observed for biomass i.e. 98.54 g m^{-2} at 0-10 cm layer and 11.16 g m^{-2} at 10-20 cm soil layer contributing 89.82% and 10.17% respectively to the total biomass in the site. Percentage contribution of density and biomass of the species to total earthworm population was 46.66% and 49.58% at 0-10 cm and 50.02% and 62.45% at 10-20 cm soil layer respectively.

Seasonal variation of density and biomass of *Eutyphoeus festivus*.

The seasonal variation of *Eutyphoeus festivus* population and biomass in the reserve forest, plantation and fallow sites are shown in **Table 10 a, b and c.**

In the reserve forest, *Eutyphoeus festivus* population was highest in the monsoon season with 69.65 m^{-2} followed by pre-monsoon and winter with 68.44 and 35.44 m^{-2} respectively. However, total biomass was maximum during pre-monsoon (75.83 g m^{-2}) followed by monsoon (55.05 g m^{-2}) and winter (30.57 g m^{-2}) season respectively. While monsoon season recorded maximum density (64.77 m^{-2}) at 0-10 cm layer, biomass (18.16 g m^{-2}) was maximum during pre-monsoon season at 10-20 cm layer. The species was not recorded at 10-20 cm soil layer during the winter season.

In the fallow site, the population density was recorded highest during pre-monsoon season (53.77m^{-2}), followed by monsoon season (41.55m^{-2}) and winter season (24.44 m^{-2}) respectively. Maximum biomass was also recorded in the pre-monsoon season with 39.97g m^{-2} followed by monsoon with 38.19g m^{-2} and winter with 8.65 g m^{-2}. At 0-10 soil layer, density and biomass were recorded during pre-monsoon (51.33 m^{-2}) and monsoon (38.19 m^{-2}) season respectively. While density and biomass were maximum during pre-monsoon season (2.44 m^{-2} and 7.50 g m^{-2} respectively), the species was not recorded during monsoon period at 10-20 cm soil layer.

In the plantation site also, monsoon season recorded the maximum population (102.77 m^{-2}) followed by pre-monsoon (65.99 m^{-2}) and winter season (46.43 m^{-2}). The trend was similar in biomass with a record of 45.67 g m^{-2} in monsoon, followed by pre-monsoon (41.24 g m^{-2}) and winter (22.77 g m^{-2}). The seasonal vertical distribution also showed a decreasing trend with increasing depth in all seasons. Monsoon season recorded a maximum density (101.55 m^{-2}) and biomass (45.16 g m^{-2}) at 0-10 cm, however, at 10-20 cm the same was recorded during pre-monsoon season (7.33 m^{-2} and 6.59 g m^{-2} respectively).

Table 10: Seasonal variation in density (Nos.m^{-2}) and biomass (gm^{-2}) of *Eutyphoeus festivus* in different sites.

Season	soil layers (cm)				Total	
	0-10		10-20		Density	Biomass
	Density	Biomass	Density	Biomass		
Winter	35.44±0.58	30.57±3.17	0	0	35.44±.58	27.80±1.74
Pre-monsoon	57.44±2.46	57.67±6.14	11±3.07	18.16±3.48	68.44±5.53	19.68±1.72
Monsoon	64.77±1.25	50.17±4.57	4.88±1.22	04.88±1.22	69.65±2.45	29.04±1.58
Annual	157.66±1.26	138.41±2.64	15.89±0.87	23.05±1.25	173.55±2.13	76.54±0.93

a) Reserve forest ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20		Density	Biomass
	Density	Biomass	Density	Biomass		
Winter	23.22±1.25	8.41±0.77	1.22±0.30	0.24±0.06	24.44±1.55	8.65±0.83
Pre-monsoon	51.33±2.02	32.47±2.05	2.44±0.35	7.50±1.76	53.77±2.37	39.97±3.81
Monsoon	41.55±1.89	38.19±3.07	0	0	41.55±1.89	38.19±3.07
Annual	116.11±1.38	79.08±1.49	3.66±.15	7.75±0.59	119.77±1.53	86.83±2.08

b) Fallow land ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20		Density	Biomass
	Density	Biomass	Density	Biomass		
Winter	42.77±3.01	18.72±1.24	3.66±0.91	4.05±1.01	46.43±3.92	22.77±2.25
Pre-monsoon	58.66±3.49	34.65±3.08	7.33±1.05	6.59±0.09	65.99±4.54	41.24±3.17
Monsoon	101.55±5.54	45.16±1.72	1.22±0.30	0.51±0.12	102.77±5.84	45.67±1.84
Annual	203±2.86	98.54±1.39	12.22±.47	11.16±0.47	215.19±3.33	109.70±1.86

c) Plantation ecosystem

Monthly variation of *Eutyphoeus festivus*

In the reserve forest, maximum and minimum density was recorded in the months of April (29.33 Nos. m^{-2}) and November (7.33 Nos. m^{-2}) respectively **(Table 12 a, b and c)**. With the initial record of 4.69 g m^{-2} during November, biomass fluctuated and attained the peak during May (44.56 g m^{-2}), thereafter it decreased showing a fluctuating trend. Monthly variation of population density at 0-10 and 10-20 cm soil layer varied from November (7.33 Nos.m^{-2}) to July (19.56 Nos. m^{-2}), and from March (1.22 Nos. m^{-2}) to April (9.77 Nos. m^{-2}) respectively. Similarly, a monthly range of biomass was 1.38 g m^{-2} (March) to 29.86 g m^{-2} (May) at 0-10 cm and 3.47 g m^{-2} (April) to 14.70 g m^{-2} (May) at 10-20 cm soil layer.

In fallow site, population density showed maximum for both density and biomass during September ((17.11 Nos. m^{-2} and 15.77 g m^{-2} respectively). At 0-10 cm, monthly population density and biomass varied from 2.44 Nos. m^{-2} and 0.86 g m^{-2} (January) to 17.11m^{-2} and 15.77 g m^{-2} (September) respectively. At 10-20 cm maximum density and biomass were recorded during 1.22 Nos. m^{-2} (November, May and June) and 7.16 g m^{-2} (June) respectively.

In the plantation site, population density and biomass was recorded maximum during August (40.44 Nos. m^{-2}) and June (15.47 g m^{-2}) respectively. Monthly population density at 0-10 cm and 10-20 cm layers varied from 6.11 Nos. m-^{2} (November) to 40.44 Nos. m^{-2} (August) and from 1.22 m^{-2} (October) to 3.66 m^{-2} respectively in the other months. Similarly, minimum and maximum biomass at 0-10 was 0.72 g m^{-2} (March) and 15.47 gm^{-2} (June) and at 10-20 cm layer it was 0.52 g m^{-2} (October) and 4.42 g m^{-2} (May).

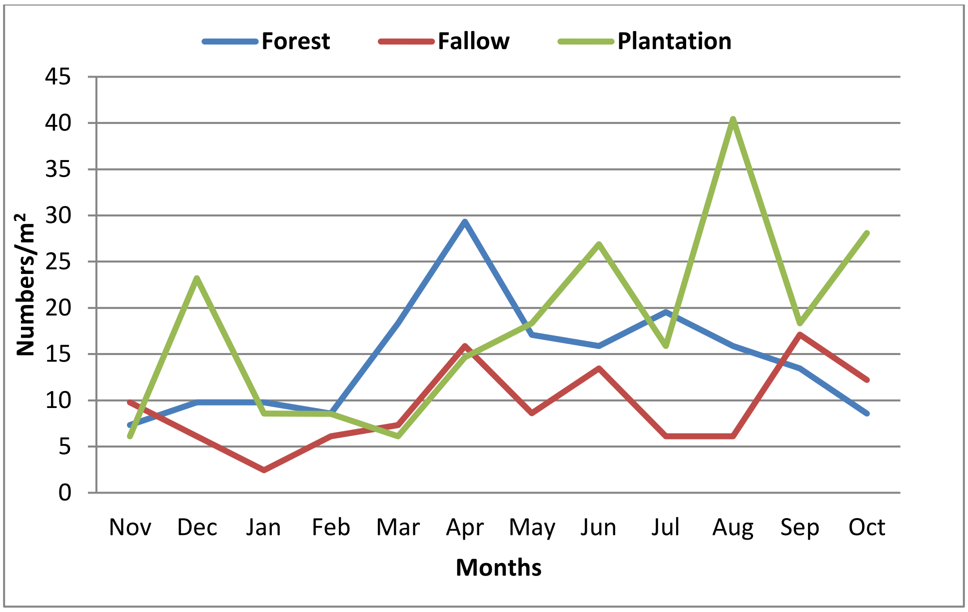


Figure 12 (a): Monthly variation of population density of *Eutyphoeus festivus* in different sites (Nos. m^{-2}).

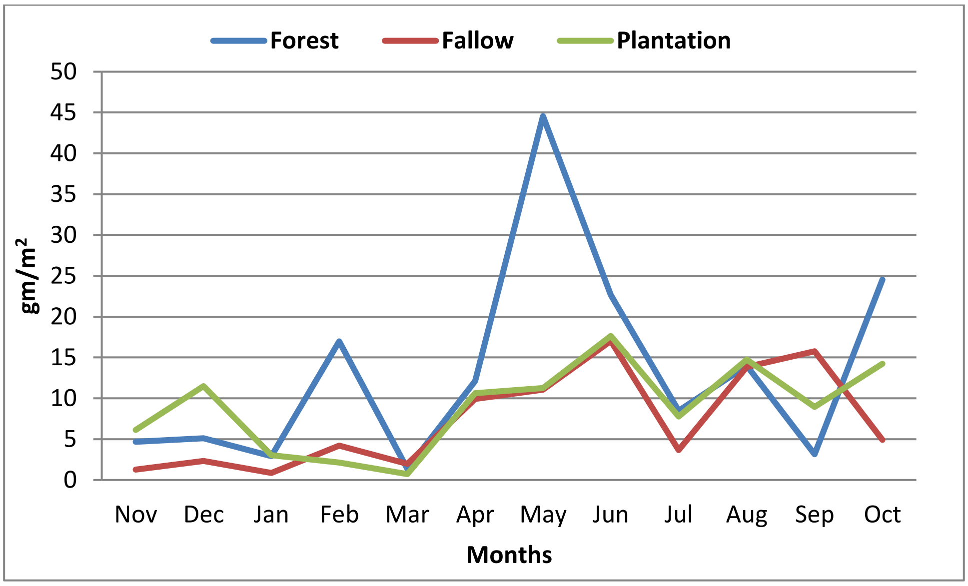


Figure 12 (b): Monthly variation of biomass of *Eutyphoeus festivus* in different sites (g m^{-2}).

ANOVA for population density

The ANOVA result of *Eutyphoeus festivus* (representing endogeic) population indicates a variation in the population density in different seasons in relation to different physico-chemical factors in all three the study sites (**Table 11 - 13**).

The ANOVA of *Eutyphoeus festivus* population in the reserve forest ecosystem exhibited significant differences between the months of pre-monsoon ($F= 6.01$, $P < 0.05$) and monsoon ($F= 5.50$, $P < 0.05$) at 0-10 cm soil layer (**Table 11**). It showed no significant variation between the months of winter ($F= 3.69$, $P > 0.05$). At 10-20 cm soil layer, no significant variation was observed between the months of annual ($F= 1.24$, $P > 0.05$).

In the fallow ecosystem the ANOVA of the species showed significant differences between the months of annual ($F= 3.51$, $P < 0.05$) at 0-10 cm but showed no significant variation between the months of winter ($F= 0.41$, $P > 0.05$), pre-monsoon ($F= 0.43$, $P > 0.05$) and monsoon ($F= 0.43$, $P > 0.05$) in the same layer (**Table 12**). At 10-20 cm soil layer, significant differences between the months of annual ($F= 9.31$, $P < 0.01$) was observed.

In the plantation ecosystem, ANOVA of *Eutyphoeus festivus* population showed significant differences between the months of pre-monsoon ($F= 7.54$, $P < 0.05$), monsoon ($F= 5.20$, $P < 0.05$) and annual ($F= 3.84$, $P < 0.05$) at 0-10 cm soil layer but it did not show any significant variation between the months of winter ($F= 2.59$, $P > 0.05$) in the same layer (**Table 13**). At the 10-20 cm soil layer, it did not exhibit significant differences between the months of pre-monsoon ($F= 0.40$, $P > 0.05$), monsoon ($F= 0.14$, $P > 0.05$) and annual ($F= 1.11$, $P > 0.05$).

Table 11: Analysis of variance (ANOVA) of *Eutyphoeus festivus* population in the forest ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	10	248.77	24.87	3.69	> 0.05
		Within the months	1	6.73	6.73		
		Total	11	255.50			
	Pre-monsoon	Between the months	7	990.43	141.49	6.01	< 0.05
		Within the months	4	94.0	23.51		
		Total	11	1084.50			
	Monsoon	Between the months	6	1883.93	313.98	5.50	< 0.05
		Within the months	5	285.13	57.02		
		Total	11	1469.06			
	Annual	Between the months	35	3390.45	47.85	**	**
		Within the months	0	0.00			
		Total	35	1674.78			
10-20	Winter	Between the months	11	NA	NA	**	**
		Within the months	0	NA	NA		
		Total	11	NA			
	Pre-monsoon	Between the months	11	0.00	18.22	**	**
		Within the months	0	0.00			
		Total	11	0.00			
	Monsoon	Between the months	11	NA	NA	**	**
		Within the months	0	NA	NA		
		Total	11	NA			
	Annual	Between the months	34	284.08	8.35	1.24	> 0.05
		Within the months	1	6.69	6.69		
		Total	35	290.78			

NA: ANOVA not computed since no earthworm was recorded.

**: ANOVA showed no result.

Table 12: Analysis of variance (ANOVA) of *Eutyphoeus festivus* population in the fallow land ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	10	248.56	24.85	0.41	> 0.05
		Within the months	1	60.50	60.50		
		Total	11	309.06			
	Pre-monsoon	Between the months	7	589.34	84.19	0.43	> 0.05
		Within the months	4	123.18	30.79		
		Total	11	712.53			
	Monsoon	Between the months	6	488.44	81.40	0.43	> 0.05
		Within the months	5	932.15	186.43		
		Total	11	1420.59			
	Annual	Between the months	15	1047.60	69.84	3.51	< 0.05
		Within the months	20	397.44	19.87		
		Total	35	1445.05			
10-20	Winter	Between the months	8	12.27	1.53	**	**
		Within the months	3	0.00	0.00		
		Total	11	12.27			
	Pre-monsoon	Between the months	8	42.39	5.29	1.78	> 0.05
		Within the months	3	8.93	2.97		
		Total	11	51.32			
	Monsoon	Between the months	4	NA	NA	**	**
		Within the months	7	NA	NA		
		Total	11	NA			
	Annual	Between the months	14	117.86	8.41	9.31	< 0.01
		Within the months	21	18.97	0.90		
		Total	35	136.83			

NA: ANOVA not computed since no earthworm was recorded

**: ANOVA showed no result.

Table 13: Analysis of variance (ANOVA) of *Eutyphoeus festivus* population in the plantation ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	8	846.71	105.83	2.59	> 0.05
		Within the months	3	122.19	40.73		
		Total	11	968.90			
	Pre-monsoon	Between the months	7	1626.67	232.38	7.54	< 0.05
		Within the months	4	123.25	30.81		
		Total	11	1749.93			
	Monsoon	Between the months	6	4737.81	789.63	5.20	< 0.05
		Within the months	5	757.94	151.58		
		Total	11	5495.75			
	Annual	Between the months	15	2789.37	185.95	3.84	< 0.05
		Within the months	20	967.72	48.38		
		Total	35	3757.09			
10-20	Winter	Between the months	8	110.91	13.86	**	**
		Within the months	3	0.00	0.00		
		Total	11	110.91			
	Pre-monsoon	Between the months	9	60.42	6.71	0.40	> 0.05
		Within the months	2	33.56	16.78		
		Total	11	93.98			
	Monsoon	Between the months	8	3.34	0.41	.14	> 0.05
		Within the months	3	8.93	2.97		
		Total	11	12.27			
	Annual	Between the months	14	98.81	7.05	1.11	> 0.05
		Within the months	21	132.53	6.31		
		Total	35	231.35			

**: ANOVA showed no result.

ANOVA for Biomass

The ANOVA of *Eutyphoeus festivus* biomass (**Table 14**) showed significant differences between the months of pre-monsoon ($F= 343.60$, $P < 0.05$), monsoon ($F= 21.41$, $P < 0.05$) and annual ($F= 7.36$, $P < 0.05$) at 0-10 cm soil layer but not between the months of winter ($F= 0.64$, $P > 0.05$). In the 10-20 cm layer, no results were shown in winter, pre-monsoon and monsoon but there was significant variation between the months of annual ($F= 8.92$, $P < 0.01$).

In the fallow ecosystem, the ANOVA of *Eutyphoeus festivus* biomass showed significant differences between the months of monsoon ($F= 19.72$, $P < 0.05$) and annual ($F= 3.66$, $P < 0.05$) at 0-10 cm but showed no significant variation between the months of winter ($F= 16.33$, $P > 0.05$) and pre-monsoon ($F= 1.07$, $P > 0.05$) in the same layer (**Table 15**). At 10-20 cm soil layer, significant differences between the months of pre-monsoon ($F= 218.16$, $P < 0.01$) was observed.

Analysis of variance (ANOVA) of *Eutyphoeus festivus* biomass in the plantation ecosystem exhibited significant variation between the months of monsoon ($F= 19.86$, $P < 0.05$) and annual ($F= 2.60$, $P < 0.05$) at 0-10 cm soil layer (**Table 16**). No significant variation was shown between the months of winter ($F= 1.81$, $P > 0.05$) and pre-monsoon ($F= 0.31$, $P > 0.05$). At 10-20 cm soil layer, significant variation was observed between the months of pre-monsoon ($F= 11.22$, $P < 0.05$) and annual ($F= 3.78$, $P < 0.05$). However no significant variation was observed between the months of winter ($F= 0.14$, $P > 0.05$) and annual ($F= 0.18$, $P > 0.05$).

Table 14: Analysis of variance (ANOVA) of biomass of *Eutyphoeus festivus* in the forest ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	10	788.72	78.87	0.64	> 0.05
		Within the months	1	121.83	121.83		
		Total	11	910.55			
	Pre-monsoon	Between the months	10	1930.36	193.03	343.60	< 0.05
		Within the months	1	0.56	0.56		
		Total	11	1930.92			
	Monsoon	Between the months	9	5434.13	603.79	21.41	< 0.05
		Within the months	2	56.37	28.18		
		Total	11	1570.51			
	Annual	Between the months	30	4944.01	164.80	7.36	< 0.05
		Within the months	5	111.82	22.36		
		Total	35	4705.84			
10-20	Winter	Between the months	8	NA	NA	**	**
		Within the months	3	NA	NA		
		Total	11	NA			
	Pre-monsoon	Between the months	11	892.76	81.16	**	**
		Within the months	0	0.00			
		Total	11	892.76			
	Monsoon	Between the months	8	NA	NA	**	**
		Within the months	3	NA	NA		
		Total	11	NA			
	Annual	Between the months	28	1108.21	39.57	8.92	< 0.01
		Within the months	7	31.04	4.43		
		Total	35	1139.26			

NA: ANOVA not computed since no earthworm was recorded.

**: ANOVA showed no result.

Table 15: Analysis of variance (ANOVA) of biomass of *Eutyphoeus festivus* in the fallow land ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	10	127.60	12.76	16.33	> 0.05
		Within the months	1	0.78	0.78		
		Total	11	128.38			
	Pre-monsoon	Between the months	7	645.91	92.27	1.07	> 0.05
		Within the months	4	342.05	85.51		
		Total	11	987.97			
	Monsoon	Between the months	6	1048.57	174.76	19.72	< 0.05
		Within the months	5	44.45	8.89		
		Total	11	1093.03			
	Annual	Between the months	15	1079.91	71.99	3.66	< 0.01
		Within the months	20	393.09	19.65		
		Total	35	1473.01			
10-20	Winter	Between the months	8	0.48	0.06	**	**
		Within the months	3	0.00	0.00		
		Total	11	0.48			
	Pre-monsoon	Between the months	8	419.48	52.43	218.16	< 0.01
		Within the months	3	0.72	0.24		
		Total	11	420.20			
	Monsoon	Between the months	4	NA	NA	**	**
		Within the months	7	NA	NA		
		Total	11	NA			
	Annual	Between the months	14	149.68	10.69	0.75	> 0.05
		Within the months	21	298.30	14.20		
		Total	35	447.98			

NA: ANOVA not computed since no earthworm was recorded.

**: ANOVA showed no result.

Table 16: Analysis of variance (ANOVA) of biomass of *Eutyphoeus festivus* in the plantation ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	8	170.38	21.29	1.81	> 0.05
		Within the months	3	35.20	11.73		
		Total	11	205.58			
	Pre-monsoon	Between the months	4	82.52	20.63	0.31	> 0.05
		Within the months	7	854.41	64.91		
		Total	11	536.94			
	Monsoon	Between the months	9	2147.17	238.57	19.86	< 0.05
		Within the months	2	24.01	12.00		
		Total	11	2171.19			
	Annual	Between the months	20	1131.10	56.55	2.60	< 0.05
		Within the months	15	325.41	21.69		
		Total	35	1456.51			
10-20	Winter	Between the months	8	37.02	4.62	0.14	> 0.05
		Within the months	3	98.73	32.91		
		Total	11	135.76			
	Pre-monsoon	Between the months	7	89.84	12.83	11.22	< 0.05
		Within the months	4	4.57	1.14		
		Total	11	94.42			
	Monsoon	Between the months	9	1.00	0.11	0.18	> 0.05
		Within the months	2	1.20	0.60		
		Total	11	2.20			
	Annual	Between the months	21	141.41	6.73	3.78	< 0.05
		Within the months	14	24.91	1.77		
		Total	35	166.33			

Annual population density and biomass of *Eutyphoeus* sp.no.1

While population density of *Eutyphoeus* sp.no.1 showed the trend of plantation > reserve forest > fallow (63.55 Nos. m^{-2} > 35.44 Nos. m^{-2} > 31.77 Nos. m^{-2}) pattern; the trend was different for biomass i.e. reserve forest > plantation > fallow **(**41.76 g m^{-2} > 31.12 g m^{-2} > 22.39 g m^{-2}) among the three sites (**Table 17 a, b and c).**

In reserve forest, the total annual population density and biomass of *Eutyphoeus* sp. no.1 was 35.44 Nos. m^{-2} and 41.76 g m^{-2} contributing 5.77 % and 7.59 % to the total earthworm population and biomass. It showed a decreasing trend with increasing soil depth i.e. 29.33 Nos. m^{-2} (82.75 %) and 6.11 Nos. m^{-2} (17.24 %) contributing 5.18 % and 12.82 % to the total earthworm density at 0-10 and 10-20 cm soil layer respectively. Biomass record was 28.10 g m^{-2} (67.28 %) and 13.66 g m^{-2} (32.71 %) contributing 5.86 % and 19.34 % to the total earthworm at 0-10 and 10-20 cm soil layer respectively.

In the fallow site, total annual population density and biomass was 31.77 Nos. m^{-2} (8.9 %) and 22.39 g m^{-2} (8.79 %) respectively. Here also, density and biomass showed a decreasing trend with increasing depth i.e. 29.33 Nos. m^{-2} (92.31 %) and 21.57 g m^{-2} (96.33 %) at 0-10 cm and 2.44 Nos. m^{-2} (7.68 %) and 0.82 g m^{-2} (3.7 %) at 10-20 cm soil layer respectively. Percentage contribution of density and biomass of the species to total earthworm population was 8.47 % and 8.81 % at 0-10 cm and 22.22 % and 8.3 % at 10-20 cm soil layer respectively.

In the plantation site, total annual population density and biomass was 63.55 Nos. m^{-2} and 31.12 g m^{-2} contributing 16.34 % and 14.36 % to the total earthworm population and biomass. The species exhibited 62.33 Nos. m^{-2} (98.08 %) and 1.22 Nos. m^{-2} (1.91 %) at 0-10 and 10-20 cm soil layer respectively. Similarly, contribution of biomass was recorded to be 30.91 g m^{-2} (99.32 %) and 0.21 g m^{-2} (0.67 %) at 0-10 and 10-20 cm soil layer. Percentage contribution of density and biomass of the species to total earthworm population was 17.1% and 15.55 % at 0-10 cm and 4.99 % and 1.17 % at 10-20 cm soil layer respectively.

Table 17: Annual total number and biomass of *Eutyphoeus* sp.no.1 in different sites.

(A=percentage contribution to the same species among the soil layers i.e. 0-10 and 10-20 cm)

(B=percentage contributions to the total earthworms in each soil layer respectively)

Density= (Numbers ± S.E. m^{-2}); Biomass= g m^{-2}

Soil layer (cm)	Density	Biomass	A		B	
	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	29.33±0.71	28.10±0.89	82.75	67.28	5.18	5.86
10-20	6.11±0.31	13.66±0.76	17.24	32.71	12.82	19.34
Annual	35.44±1.02	41.76±1.65	100	100	5.77	7.59

a) **Reserve forest ecosystem**

Soil layer (cm)	Density	Biomass	A		B	
	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	29.33±0.61	21.57±0.50	92.31	96.33	8.47	8.81
10-20	2.44±0.13	0.82±0.04	7.68	3.7	22.22	8.3
Annual	31.77±0.74	22.39±0.54	100	100	8.9	8.79

b) **Fallow land ecosystem**

Soil layer (cm)	Density	Biomass	A		B	
	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	62.33±1.15	30.91±0.76	98.08	99.32	17.1	15.55
10-20	1.22±0.10	0.21±0.01	1.91	0.67	4.99	1.17
Annual	63.55±1.25	31.12±0.77	100	100	16.34	14.36

c) **Plantation ecosystem**

Seasonal variation of density and biomass of *Eutyphoeus* sp. no.1

The seasonal variations of *Eutyphoeus* sp.no.1 population density and biomass for reserve forest, plantation and fallow ecosystem are shown in **Table 18 a, b and c.**

In the reserve forest ecosystem, the total population density of *Eutyphoeus* sp.no.1 was highest during monsoon season (17.11 Nos. m^{-2}), followed by pre-monsoon season (14.66 Nos. m^{-2}) and winter season (3.66 Nos. m^{-2}) respectively. However, maximum biomass was recorded in pre-monsoon (23.22 g m^{-2}) followed by monsoon (9.79 g m^{-2}) and winter (8.73 g m^{-2}). This could be due to the collection of bigger earthworms during the sampling period. Among soil layers, maximum density was recorded in 0-10 cm during monsoon season (15.88 m^{-2}) and the minimum was recorded in 10-20 cm during winter and rainy season (1.22 g m^{-2}). While pre-monsoon season recorded maximum biomass (14.40 g m^{-2}) at 0-10 cm layer, it was minimum during monsoon season (1.24 g m^{-2}) at 10-20 cm layer.

In the fallow site, both population density and biomass was recorded maximum during pre-monsoon season (14.66 Nos. m^{-2} and 12.65 g m^{-2}) followed by monsoon season (11 Nos. m^{-2} and 7.07 g m^{-2}) and winter season (6.11 Nos. m^{-2} and 2.67 g m^{-2}). At 0-10 soil layer, density and biomass were recorded to be maximum during pre-monsoon (12.22 Nos. m^{-2} and 11.83 g m^{-2}) and minimum during winter (6.11 Nos. m^{-2} and 2.67 g m^{-2}) season respectively. However, at 10-20 cm the species was recorded only during pre-monsoon season (2.44 Nos. m^{-2} and 0.82 g m^{-2}).

In the plantation site, monsoon season recorded the maximum population (35.44 Nos. m^{-2}) followed by pre-monsoon (18.33 Nos. m^{-2}) and winter season (9.77 Nos. m^{-2}). The trend was similar in biomass also with a record of 20.14 g m^{-2} in monsoon, followed by pre-monsoon

(10.06 g m^{-2}) and winter (0.92 g m^{-2}). Except for the pre-monsoon season (1.22 Nos. m^{-2} and 0.21 g m^{-2}), the species was not recorded at 10-20 cm layer. At 0-10 cm layer, both density and biomass recorded the highest count during monsoon (35.44 Nos. m^{-2} and 20.14 g m^{-2}) and minimum during the winter period (9.77 Nos. m^{-2} and 0.92 g m).

Monthly variation of *Eutyphoeus* sp.no.1

In the reserve forest, the species was not recorded from December to April. However, at 0-10 cm the species recorded 7.33 Nos. m^{-2} and 10.51 g m^{-2} (May) showing fluctuating trend thereafter. At 10-20 cm the species was recorded during November (1.22 Nos. m^{-2}), May (3.67 Nos. m^{-2}) and October (1.22 Nos. m^{-2}) respectively.

In fallow site, population density and biomass showed a single peak during February (6.11 Nos. m^{-2}) and May (4.77 g m^{-2}) respectively at 0-10 cm layer. At 10-20 cm, May and June recorded this species (1.22 Nos. m^{-2}) showing negligible biomass (.45 g m^{-2}). The species was not recorded from November to January.

In the plantation site, population density and biomass recorded maximum during August (14.66 Nos. m^{-2} and 7.42 g m^{-2} respectively). Monthly population density at 0-10 cm layer varied from 1.22 Nos. m^{-2} (January) to 14.66 Nos. m^{-2} (August), however at 10-20 cm, it was recorded only during May (1.22 Nos. m^{-2}) having no record of earthworm in other months. Similarly, minimum and maximum biomass at 0-10 cm layer were recorded as 0.21 g m^{-2} (January) and 7.42 g m^{-2} (August) and at 10-20 cm layer, it was 0.21 g m^{-2} during May.

The variable microclimatic conditions could be the plausible reasons for the sporadic presence of the species.

Table 18: Seasonal variation in density (Nos.m^{-2}) and biomass (g m^{-2}) of *Eutyphoeus* sp.no.1 in different sites.

Season	soil layers (cm)				Total	
	0-10		10-20			
	Density	Biomass	Density	Biomass	Density	Biomass
Winter	2.44±0.61	5.14±1.28	1.22±0.30	3.59±0.89	3.66±0.91	8.73±2.17
Pre-monsoon	11±1.75	14.40±2.47	3.66±1.94	8.82±2.20	14.66±3.69	23.22±4.67
Monsoon	15.88±0.58	8.55±0.27	1.22±0.30	1.24±0.31	17.1±0.88	9.79±0.58
Annual	29.33±0.71	28.10±0.89	6.11±0.31	13.66±0.76	35.44±1.02	41.76±1.65

a) Reserve forest ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20			
	Density	Biomass	Density	Biomass	Density	Biomass
Winter	6.11±1.52	2.67±0.66	0	0	6.11±1.52	2.67±0.66
Pre-monsoon	12.22±0.78	11.83±0.97	2.44±0.35	0.82±0.12	14.66±1.13	12.65±1.09
Monsoon	11.00±1.93	7.07±0.77	0	0	11.00±1.93	7.07±0.77
Annual	29.33±0.61	21.57±0.50	2.44±0.13	0.82±0.04	31.77±0.74	22.39±0.54

b) Fallow land ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20			
	Density	Biomass	Density	Biomass	Density	Biomass
Winter	9.77±1.15	0.92±0.08	0	0	9.77±1.15	0.92±0.08
Pre-monsoon	17.11±1.17	9.85±1.00	1.22±0.30	0.21±0.05	18.33±1.47	10.06±1.05
Monsoon	35.44±2.19	20.14±1.25	0	0	35.44±2.19	20.14±1.25
Annual	62.33±1.15	30.91±0.76	1.22±0.30	0.21±0.01	63.55±1.25	31.12±0.77

c) Plantation ecosystem

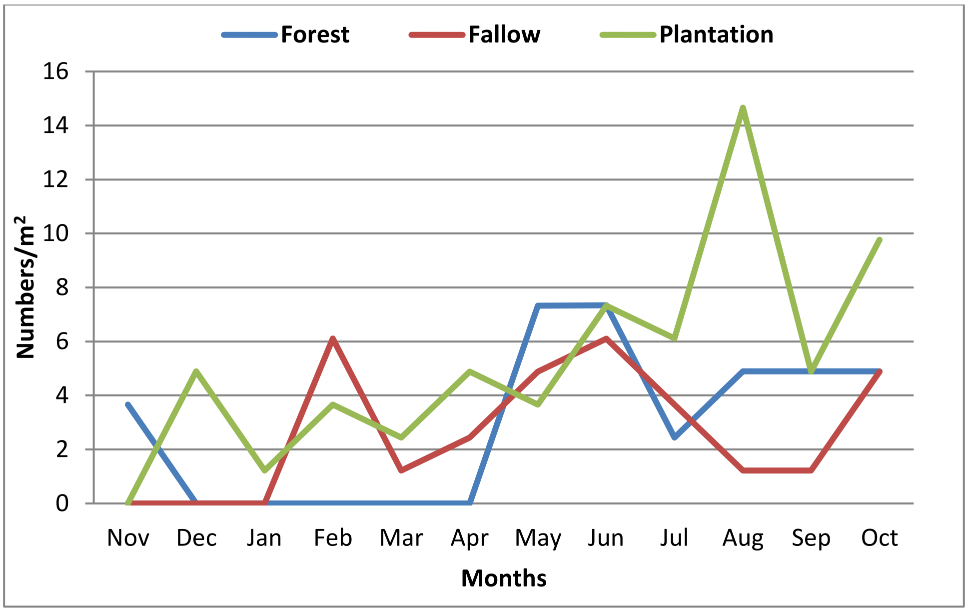


Figure 13 (a): Monthly variation of population density of *Eutyphoeus* sp.no.1 in different sites (Nos. m^{-2}).

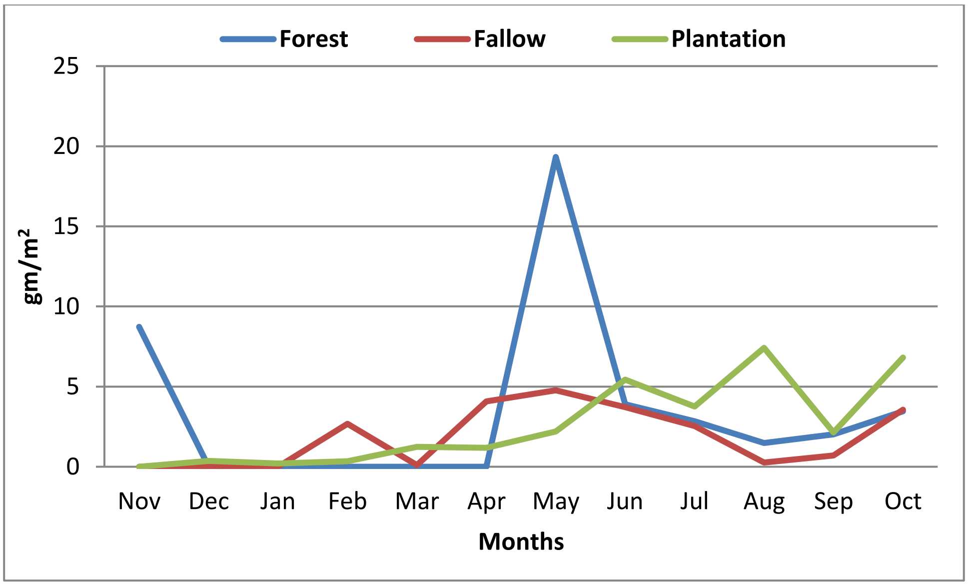


Figure 13 (b): Monthly variation of biomass of *Eutyphoeus* sp.no.1 in different sites (g m^{-2}

Annual population density and biomass of *Eutyphoeus marmoreus*

The total annual population density of *Eutyphoeus marmoreus* and its vertical distribution in the different soil layers showed the highest in reserve forest (45.21 Nos. m^{-2}) contributing 7.36 % to the total population density of the earthworms, followed by fallow land with 8.55 Nos. m^{-2} and plantation sites with 7.33 Nos. m^{-2} contributing 2.39 % and 1.88 % to the total earthworms population respectively**.** Correspondingly, the total annual biomass of the species was the highest in the reserve forest site (61.68 g m^{-2}), followed by the fallow site (21.45 g m^{-2}) and the plantation site (6.47 g m^{-2}) respectively **(Table 19 a, b and c).**

In the reserve forest, maximum *Eutyphoeus marmoreus* population was recorded in the 0-10 cm soil layer with 40.33 Nos. m^{-2}, contributing 89.2 % to the total population of the species in the same layer and 7.12 % to the total earthworm population. The maximum biomass was recorded in 0-10 cm soil layer (50.04 g m^{-2}) which in turn contributed 10.44 % to the total biomass in the site. 4.88 Nos. m^{-2} was collected, contributing 10.79 % to the total population of the species in the 10-20 cm soil layer and 10.24 % to the total earthworm population while in the same layer biomass was 11.64 g m^{-2} contributing 16.48 % to the total biomass recorded.

In fallow site, the species recorded in the 0-10 cm layer was 8.55 Nos. m^{-2} contributing 100 % to the species population and 2.47 % to the total earthworm population. Total biomass record at 0-10 cm layer was 21.45 g m^{-2} contributing 8.76 % to the total biomass. The species was not recorded at 10-20 cm layer.

In the plantation site population density of the species at 0-10 and 10-20 cm was 6.11 Nos. m^{-2} and 1.22 Nos. m^{-2} contributing 83.35 % and 16.64 % to the total *Eutyphoeus marmoreus* population in the respective soil layers and contributed 1.67 and 4.99 % to the total earthworm population respectively. The total biomass of the species at the 0-10 cm layer was 6.26 g m^{-2} contributing 3.15% to the total biomass count while 10-20 cm soil layer recorded only 0.21 g m^{-2} of *Eutyphoeus marmoreus* biomass which contributed a low 1.17 % to the total biomass.

Table 19: Annual total number and biomass of *Eutyphoeus marmoreus* in different sites.

(A=percentage contribution to the same species among the soil layers i.e. 0-10 and 10-20 cm)
(B=percentage contributions to the total earthworms in each soil layer respectively)

Density= (Numbers ± S.E. m^{-2}); Biomass= g m^{-2}

	Density	Biomass	A		B	
Soil layer (cm)	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	40.33±0.31	50.04±1.20	89.2	81.12	7.12	10.44
10-20	4.88±0.31	11.64±0.92	10.79	18.87	10.24	16.48
Annual	45.21±1.04	61.68±2.12	100	100	7.36	11.21

a) Reserve forest ecosystem

	Density	Biomass	A		B	
Soil layer (cm)	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	8.55±0.34	21.45±1.15	100	100	2.47	8.76
10-20	0	0	0	0	0	0
Annual	8.55±0.34	21.45±1.15	100	100	2.39	8.42

b) Fallow land ecosystem

	Density	Biomass	A		B	
Soil layer (cm)	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	6.11±0.27	6.26±0.27	83.35	96.75	1.67	3.15
10-20	1.22±0.10	0.21±0.01	16.64	3.24	4.99	1.17
Annual	7.33±0.37	6.47±0.28	100	100	1.88	2.98

c) Plantation ecosystem

Seasonal variations of *Eutyphoeus marmoreus*

The seasonal variation of *Eutyphoeus marmoreus* population density and biomass in the different ecosystems is shown in **Table 20 a, b and c**. Reserve forest recorded the highest density of 15.88 Nos. m^{-2} in pre-monsoon and monsoon, fallow land recorded a high of 8.55 Nos. m^{-2} in monsoon and plantation recorded 3.66 Nos. m^{-2} in pre-monsoon. For biomass, in reserve forest, highest record was in pre-monsoon (31.23 g m^{-2}), while in the fallow ecosystem, monsoon recorded the highest (21.45 g m^{-2}) whereas plantation recorded the maximum biomass count in pre-monsoon (4.23 g m^{-2}).

In the forest ecosystem, at 0-10 cm soil layer, monsoon recorded the highest for both density and biomass with 15.88 Nos. m^{-2} and 24.55 g m^{-2} respectively. However, the total population of the species showed 15.88 Nos. m^{-2} each for both the pre-monsoon and monsoon seasons respectively when 0-20 cm soil layer was considered. At 0-10 cm layer, biomass for pre-monsoon was 20.06 g m^{-2} while winter recorded 14.42 g m^{-2}. In the 10-20 cm soil layers no population of the species was recorded in monsoon season. Further, the highest biomass count was in pre-monsoon (11.17 g m^{-2}), followed by winter (0.47 g m^{-2}) in the same soil layer.

Interestingly in the fallow ecosystem, only monsoon season recorded density of 8.55 Nos. m^{-2} and biomass of 21.45 g m^{-2} for the species, with no collections in the winter and pre-monsoon seasons. The 10-20 cm soil layer did not record any *Eutyphoeus marmoreus* species in any of the three seasons. Though less in number, their presence could be attributed to the good moisture content during the monsoon season.

In the plantation ecosystem, pre-monsoon recorded the highest density (3.66 Nos. m^{-2}) and biomass (4.23 g m^{-2}) for *Eutyphoeus marmoreus* in all the soil layers. The biomass count recorded for monsoon was 2.03 g m^{-2} at 0-10 cm soil layer. In the same layer, the winter season did not record the species. On the contrary, in the 10-20 cm soil layer 1.22 Nos. m^{-2} *Eutyphoeus marmoreus* count was recorded with biomass of 0.21 g m^{-2} during the winter season.

Table 20: Seasonal variation in density (Nos.m^{-2}) and biomass (g m^{-2}) of *Eutyphoeus marmoreus* in different sites.

Season	soil layers (cm)				Total	
	0-10		10-20		Density	Biomass
	Density	Biomass	Density	Biomass		
Winter	12.22±1.05	14.42±1.03	1.22±0.30	0.47±0.11	13.44±1.35	14.89±1.14
Pre-monsoon	12.22±0.61	20.06±2.28	3.66±0.91	11.17±2.79	15.88±1.52	31.23±5.07
Monsoon	15.88±2.07	24.55±2.93	0	0	15.88±2.07	24.55±2.93
Annual	40.33±0.73	50.04±1.20	4.88±0.31	11.64±0.92	45.21±1.04	61.68±2.12

a) Reserve forest ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20		Density	Biomass
	Density	Biomass	Density	Biomass		
Winter	0	0	0	0	0	0
Pre-monsoon	0	0	0	0	0	0
Monsoon	8.55±0.34	21.45±2.86	0	0	8.55±0.34	21.45±2.86
Annual	8.55±0.34	21.45±1.15	0	0	8.55±0.34	21.45±1.15

b) Fallow land ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20		Density	Biomass
	Density	Biomass	Density	Biomass		
Winter	0	0	1.22±.30	0.21±0.10	1.22±0.30	0.21±0.10
Pre-monsoon	3.66±0.58	4.23±0.61	0	0	3.66±0.58	4.23±0.61
Monsoon	2.44±0.61	2.03±0.50	0	0	2.44±0.61	2.03±0.50
Annual	6.11±0.27	6.26±0.27	1.22±0.10	0.21±0.01	7.33±0.37	6.47±0.28

c) Plantation ecosystem

Monthly variation of *Eutyphoeus marmoreus*

The monthly variation of *Eutyphoeus marmoreus* showed fluctuations in all the three sites for both density and biomass **(Figure 14 a and b).** For reserve forest, maximum density and biomass were recorded in September (9.78 Nos. m^{-2}) and October (12.82 gm^{-2}) respectively. In the plantation ecosystem, June and July recorded the highest density with 2.44 Nos. m^{-2} while biomass peaked in April (2.37 g m^{-2}). However, in the fallow ecosystem, September recorded the highest density and biomass in September (3.66 Nos. m^{-2} and 13.76 g m^{-2}) respectively.

In the reserve forest ecosystem, only August did not record the species in the 0-10 cm soil layer. Overall, September (9.78 Nos. m^{-2}) was the peak month for density and for biomass it was June (13.60 g m^{-2}). In the 10-20 cm soil layer, only two months i.e. December and June observed the species with a count of 1.22 Nos. m^{-2} and 3.67 Nos. m^{-2} respectively, with June recording higher biomass of 11.17 g m^{-2}.There was no collection of the species in the other months.

The fallow ecosystem did not record any *Eutyphoeus marmoreus* species in the 10-20 cm soil layers. Even in the 0-10 cm soil layers only four months i.e. July, August, September and October, recorded *Eutyphoeus marmoreus* with the highest density and biomass in September (3.66 Nos. m^{-2} and 13.76 g m^{-2}) respectively.

Plantation ecosystem showed *Eutyphoeus marmoreus* collection only in the months of April, June and July in the 0-10 cm soil layers with 1.22, 2.44 and 2.44 Nos. m^{-2} respectively wherein biomass count in April (2.37 g m^{-2}) was the highest. For the 10-20 cm soil layer, only December recorded the species with 1.22 Nos. m^{-2} density and 0.21 g m^{-2} biomass respectively.

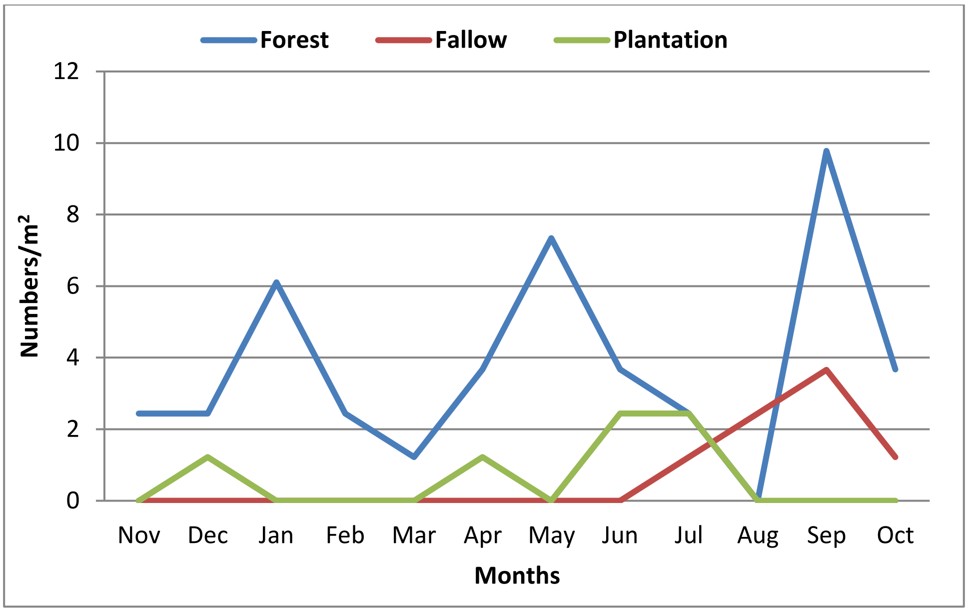


Figure 14 (a): Monthly variation of population density of *Eutyphoeus marmoreus* in different sites (Nos. m^{-2}).

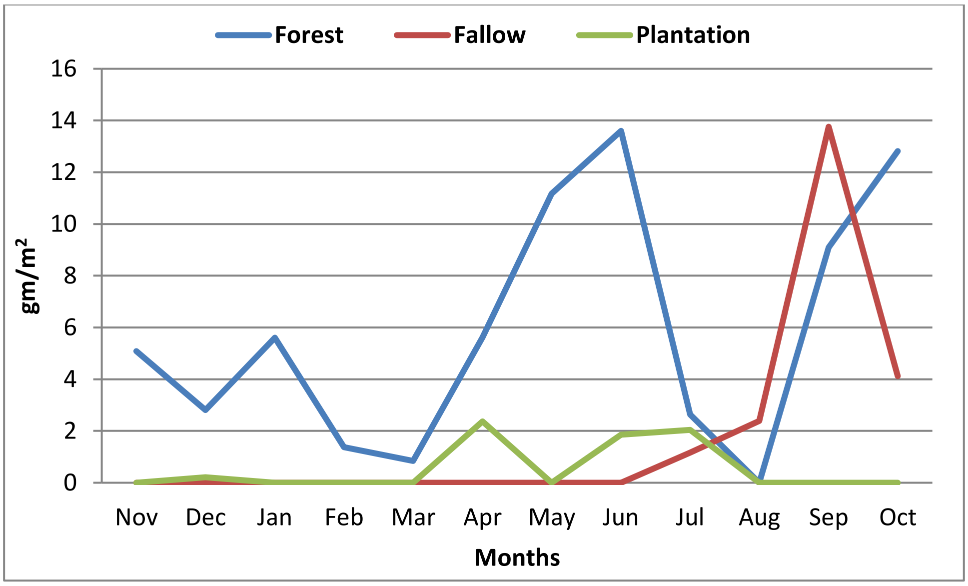


Figure 14 (b): Monthly variation of biomass of *Eutyphoeus marmoreus* in different sites (g m^{-2}).

Annual population density and biomass of *Amynthas corticis*

The annual total population density of *Amynthas corticis* showed that reserve forest (39.11 Nos. m^{-2}) accumulated the highest density followed by fallow (4.88 Nos. m^{-2}) and plantation (2.44 Nos. m^{-2}) as shown in **Table 21 a, b and c.** The biomass was highest for forest (38.21 g m^{-2}) but it was followed by plantation (2.04 g m^{-2}) and fallow (1.68 g m^{-2}). Only 0-10 cm soil layer recorded the species in all the three sites.

In the reserve forest, 39.11 Nos. m^{-2} of *Amynthas corticis* population was recorded in the 0-10 cm soil layer which contributed to 6.37 % of the total earthworm population while the annual biomass of the species was 38.21 g m^{-2} contributing 7.97 % to the total earthworm biomass.

The fallow site recorded 4.88 Nos. m^{-2} of the species contributing 1.36 % to the total earthworm population and only 1.68 g m^{-2} of biomass which contributed only 0.68 % to the total earthworm biomass.

The plantation site also showed similar readings with 2.44 Nos. m^{-2} of *Amynthas corticis* species density in the 0-10 cm soil layer contributing a very low .62 % to the total earthworm population and 2.04 g m^{-2} of biomass which contributed 1.02 % to the total earthworm biomass.

Among the three sites *Amynthas corticis* population contribution to the total earthworm was the highest in the reserve forest (6.37 %) followed by fallow (1.36 %) and plantation site (0.62 %) respectively.

Table 21: Annual total number and biomass of *Amynthas corticis* in different sites.

(A=percentage contribution to the same species among the soil layers i.e. 0-10 and 10-20 cm)

(B=percentage contributions to the total earthworms in each soil layer respectively)

Density= (Numbers ± S.E. m^{-2}); Biomass= g m^{-2}

Soil layer (cm)	Density	Biomass	A		B	
	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	39.11±1.01	38.21±0.96	100	100	6.9	7.97
10-20	0	0	0	0	0	0
Annual	39.11±1.01	38.21±0.96	100	100	6.37	6.94

a) Reserve forest ecosystem

Soil layer (cm)	Density	Biomass	A		B	
	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	4.88±0.22	1.68±0.08	100	100	1.41	0.68
10-20	0	0	0	0	0	0
Annual	4.88±0.22	1.68±0.08	100	100	1.36	0.65

b) Fallow land ecosystem

Soil layer (cm)	Density	Biomass	A		B	
	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	2.44±0.13	2.04±0.11	100	100	0.66	1.02
10-20	0	0	0	0	0	0
Annual	2.44±0.13	2.04±0.11	100	100	0.62	0.94

c) Plantation ecosystem

Seasonal variations of *Amynthas corticis*

The seasonal variations in density and biomass of *Amynthas corticis* in the reserve forest, plantation and fallow ecosystems are shown in **Table 22 a, b and c.**

In the reserve forest ecosystem, monsoon season recorded the maximum population with 24.44 Nos. m^{-2} followed by pre-monsoon season with 9.77 Nos. m^{-2} and winter season with 4.88 Nos. m^{-2}. In contrast, pre-monsoon recorded the maximum biomass count (19.93 g m^{-2}) followed by the monsoon season with 16.58 g m^{-2} and winter season with 1.69 g m^{-2} respectively. No species was recorded at 10-20 cm soil layer in any of the three seasons.

In the fallow ecosystem also, unlike forest site, winter recorded the maximum count of *Amynthas corticis* species with 2.44 Nos. m^{-2} followed by monsoon and pre-monsoon (1.22 Nos. m^{-2} each) respectively. But monsoon season showed the highest biomass of (0.95 g m^{-2}) which was followed by the winter season (0.59 g m^{-2}) and pre-monsoon season (0.13 g m^{-2}) respectively.

In the plantation ecosystem, winter season recorded the highest density of 2.44 Nos. m^{-2} which corresponded with the highest biomass count (2.04 g m^{-2}) in the 0-10 cm soil layer. There was no recording of the *Amynthas corticis* species in the monsoon and pre-monsoon seasons at 0-10 cm soil layer.

Table 22: Seasonal variation in density (Nos.m^{-2}) and biomass (gm^{-2}) of *Amynthas corticis* in different sites.

Season	soil layers (cm)				Total	
	0-10		10-20			
	Density	Biomass	Density	Biomass	Density	Biomass
Winter	4.88±0.86	1.69±0.27	0	0	4.88±0.86	1.69±0.27
Pre-monsoon	9.77±0.86	19.93±2.09	0	0	9.77±0.86	19.93±2.09
Monsoon	24.44±2.34	16.58±1.41	0	0	24.44±2.34	16.58±1.41
Annual	39.11±1.01	38.21±0.96	0	0	39.11±1.01	38.21±0.96

a) Reserve forest ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20			
	Density	Biomass	Density	Biomass	Density	Biomass
Winter	2.44±0.61	0.59±0.14	0	0	2.44±0.61	0.59±0.14
Pre-monsoon	1.22±0.30	0.13±0.03	0	0	1.22±0.30	0.13±0.03
Monsoon	1.22±0.30	0.95±0.23	0	0	1.22±0.30	0.95±0.23
Annual	4.88±0.22	1.68±0.08	0	0	4.88±0.22	1.68±0.08

b) Fallow land ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20			
	Density	Biomass	Density	Biomass	Density	Biomass
Winter	2.44±0.35	2.04±0.30	0	0	2.44±0.35	2.04±0.30
Pre-monsoon	0	0	0	0	0	0
Monsoon	0	0	0	0	0	0
Annual	2.44±0.13	2.04±0.11	0	0	2.44±0.13	2.04±0.11

c) Plantation ecosystem

Monthly variation of *Amynthas corticis*

The monthly total population of *Amynthas corticis* as indicated in **Figure 15 a and b** shows that reserve forest collected the highest number in September (12.22 Nos. m^{-2}) whereas plantation and fallow site showed the sporadic presence of the species during the sampling period. Biomass count in the different sites was also quite low.

In the reserve forest ecosystem, at 0-10 cm soil layer three months i.e. January, February and June did not record any *Amynthas corticis* species. The density ranged from 1.22 Nos. m^{-2} (December) to 12.22 Nos. m^{-2} (September) at 0-10 cm soil layer. In the same layer, April (10.15 g m^{-2}) and August (8.04 g m^{-2}) recorded the highest biomass.

In the fallow site, February recorded the highest species count (2.44 Nos. m^{-2}). April and October also recorded *Amynthas corticis* individuals in the 0-10 cm soil layers (1.22 Nos. $m^{-2)}$ wherein, the month of October recorded the maximum biomass (0.95 g m^{-2}).

In the plantation site, only November and January showed *Amynthas corticis* individuals (1.22 Nos.m^{-2} each) with November recording the highest biomass count (1.22 g m^{-2}). No peak period could be indicated properly. The rest of the months did not record any individual of the species.

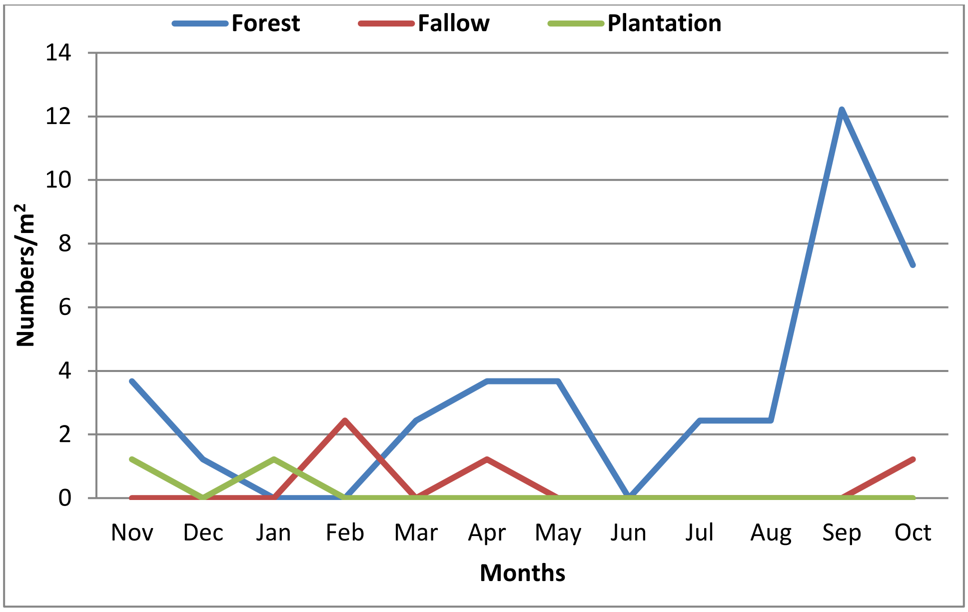


Figure 15 (a): Monthly variation of population density of *Amynthas corticis* in different sites (Nos. m^{-2}).

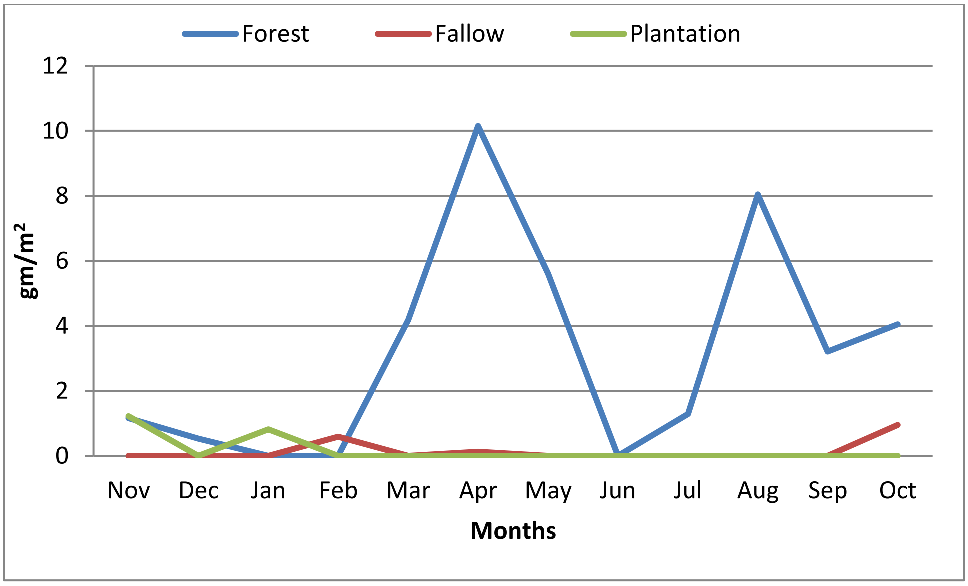


Figure 15 (b): Monthly variation of biomass of *Amynthas corticis* in different sites (g m^{-2}).

Annual population density and vertical distribution of *Amynthas* sp.1

The annual population of *Amynthas* sp.1 was recorded only in the reserve forest ecosystem at 0-10 cm soil layer (11 Nos. m^{-2}) contributing 100% to the species and 1.79 % to the total earthworm population. The biomass of the species was 15.90 g m^{-2} which contributed 3.31 % 0-10 cm soil layer and 2.89 % to the total earthworm population **(Table 23 a).** The species not recorded in 10-20 cm soil layer.

Amynthas sp.1 population was not recorded in the remaining two ecosystems i.e. plantation and fallow.

Seasonal variations of *Amynthas* sp.1

The species was recorded during monsoon period only exhibiting total population density and biomass of 11 Nos. m^{-2} and biomass of 15.90 g m^{-2} respectively **(Table 24 a)**.

Monthly variation of *Amynthas* sp.1

The species was recorded in reserve forest from July (1.22 Nos. m^{-2}) to September and October (3.67 Nos. m^{-2}) i.e. during monsoon period only. Similarly monthly biomass varied from 1.32 g m^{-2} (July) to 5.68 g m^{-2} (August). (**Figure 16 a and b).**

Table 23: Annual total number and biomass of *Amynthas* sp.1 in different sites.

(A=percentage contribution to the same species among the soil layers i.e. 0-10 and 10-20 cm)

(B=percentage contributions to the total earthworms in each soil layer respectively)

Density= (Numbers ± S.E. m^{-2}); Biomass= g m^{-2}

Soil layer (cm)	Density	Biomass	A		B	
	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	11.00±0.42	15.90±0.63	100	100	1.94	3.31
10-20	0	0	0	0	0	0
Annual	11.00±0.42	15.90±0.63	100	100	1.79	2.89

a) Reserve forest ecosystem

Table 24: Seasonal variation in density (Nos.m^{-2}) and biomass (g m^{-2}) of *Amynthas* sp.1 in different sites.

Season	soil layers (cm)				Total	
	0-10		10-20			
	Density	Biomass	Density	Biomass	Density	Biomass
Winter	0	0	0	0	0	0
Pre-monsoon	0	0	0	0	0	0
Monsoon	11.00±0.58	15.90±0.94	0	0	11.00±0.58	15.90±0.94
Annual	11.00±0.42	15.90±0.63	0	0	11.00±0.42	15.90±0.63

a) Reserve forest ecosystem

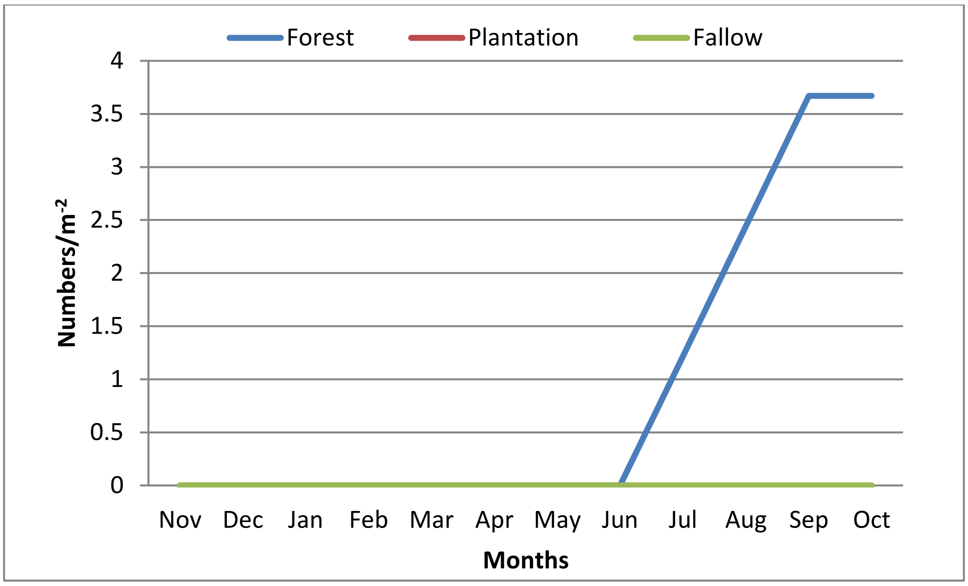


Figure 16 (a): Monthly variation of population density of *Amynthas* sp.1 in different sites (Nos. m^{-2}).

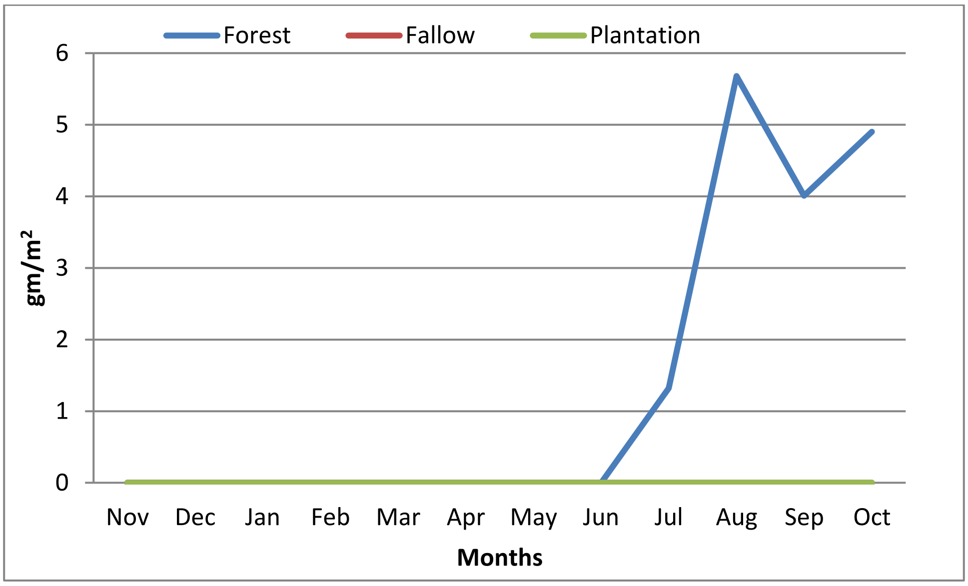


Figure 16 (b): Monthly variation of biomass of *Amynthas* sp.1 in different sites (g m^{-2}).

Annual population density and biomass of *Drawida* sp.

The total annual population density and biomass of *Drawida* sp. in the different soil layers of the reserve forest, plantation and fallow ecosystems are shown in **Table 25 a, b and c.** The annual density was found to be slightly higher in fallow land (156.54 Nos.m^{-2}) followed by forest (151 Nos. m^{-2}) and plantation (109.99 Nos. m^{-2}). But the annual biomass was highest in the natural forest (154.32 g m^{-2}) followed by the fallow ecosystem (102.92 g m^{-2}) and then eventually the plantation site (63.53 g m^{-2}).

In the reserve forest ecosystem, the annual population density of *Drawida* sp. was 151 Nos. m^{-2}, contributing 24.69 % of the total earthworm population. The population density showed a decreasing trend with increasing soil depth i.e.135.66 Nos. m^{-2} (contributing 89.52 %) at 0-10 cm, and 15.88 Nos. m^{-2} (contributing 10.47 %) at the 10-20 cm layers. The annual biomass of *Drawida* sp. in the 0-10 cm and 10-20 cm soil layer was 132.04 g m^{-2} (contributing 27.55 % to the total earthworm biomass) and 22.28 g m^{-2} (contributing 31.54 % to the total earthworm biomass) in the respective soil layers. Further, it contributed 23.96 % and 33.31 % to the total earthworm population at 0-10 cm and 10-20 cm soil layers respectively. Overall, it contributed to 24.69 % and 28.08 % to the total earthworm density and biomass in the site.

In the fallow ecosystem, the total annual population density of *Drawida* sp. was 156.54 Nos. m^{-2} which contributed 43.85 % to the total earthworm population. The population density of the species showed a decreasing trend with the increase in soil depth i.e. 151.66 Nos. m^{-2} (96.88 %) at 0-10 cm and 4.88 Nos. m^{-2} (4.88 %) at 10-20 cm layers. It further contributed 43.83 % and 44.44 % to the total earthworm population at 0-10 cm and 10-20 cm soil layers respectively. The biomass at 0-10 cm soil layer was 101.62 g m^{-2}

(contributing 41.52 % to the total earthworm biomass) and 1.30 g m^{-2} (contributing 13.17 % to the total earthworm biomass) at 10-20 cm layer.

In plantation ecosystem, the total annual density and biomass of *Drawida* sp. was 109.99 Nos. m^{-2} and 63.53 g m^{-2} which contributed 28.29 % and 29.33 % to the total earthworm density and biomass respectively. Population density of the species was 101.44 Nos. m^{-2} (92.22 %) at 0-10 cm and 8.55 Nos. m^{-2} (7.77 %) at 10-20 cm layers. Similarly, at 0-10 cm and 10-20 cm layer, biomass was 57.47 g m^{-2} and 6.06 g m^{-2} which contributed 28.91 % and 33.91 % to the total earthworm biomass in the site. Further, the species contributed 27.84 % and 34.99 % to the total earthworm density at 0-10 cm and 10-20 cm soil layers. It also showed a similar trend of decreasing biomass with increasing soil depth.

Table 25: Annual total number and biomass of *Drawida* sp in different sites.

(A=percentage contribution to the same species among the soil layers i.e. 0-10 and 10-20 cm)

(B=percentage contributions to the total earthworms in each soil layer respectively)

Density= (Numbers ± S.E. m^{-2}); Biomass= g m^{-2}

	Density	Biomass	A		B	
Soil layer (cm)	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	135.66±2.10	132.04±3.15	89.52	85.56	23.96	27.55
10-20	15.88±0.90	22.28±1.17	10.47	14.43	33.32	31.54
Annual	151.54±3.00	154.32±4.32	100	100	24.69	28.08

a) Reserve forest ecosystem

	Density	Biomass	A		B	
Soil layer (cm)	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	151.66±2.93	101.62±2.63	96.88	98.73	43.83	41.52
10-20	4.88±0.17	1.30±0.04	3.11	1.26	44.44	13.17
Annual	156.54±3.10	102.92±2.67	100	100	43.85	40.42

b) Fallow land ecosystem

	Density	Biomass	A		B	
Soil layer (cm)	Nos.m^{-2}±S.E	g m^{-2}±S.E	Density	Biomass	Density	Biomass
0-10	101.44±2.44	57.47±1.76	92.22	90.46	27.84	28.91
10-20	8.55±0.50	6.06±0.39	7.77	9.53	34.99	33.91
Annual	109.99±2.94	63.53±2.15	100	100	28.29	29.33

c) Plantation ecosystem

Seasonal variation of density and biomass of *Drawida* sp.

The seasonal variation of *Drawida* sp. population exhibited the highest count in monsoon seasons in the reserve forest (61.10 Nos. m^{-2}), fallow (90.44 Nos. m^{-2}) and plantation (48.88 Nos. m^{-2}) ecosystems respectively. However for biomass, the maximum count in plantation site was in the pre-monsoon season (28.73 g m^{-2}) while in the forest and the fallow sites monsoon season gathered the maximum biomass with 77.94 g m^{-2} and 61.85 g m^{-2} respectively (**Table 26 a, b and c**).

In the reserve forest ecosystem, the population density of *Drawida* sp. recorded the maximum in the monsoon season (61.10 Nos. m^{-2}) followed by pre-monsoon with 59.88 Nos. m^{-2} and winter with 30.55 Nos. m^{-2} respectively. The vertical distribution during the different seasons showed a decreasing trend with the increase in soil depth. In the 0-10 cm layer, the maximum density was recorded in the monsoon season (59.88 Nos. m^{-2}) followed by pre-monsoon (46.44 Nos. m^{-2}) and winter (29.33 Nos. m^{-2}). The pattern was similar for biomass also with a maximum in monsoon (76.96 g m^{-2}), followed by pre-monsoon (43.76 g m^{-2}) and then winter (11.31 g m^{-2}) respectively. However, in the 10-20 cm soil layer, the maximum count was in the pre-monsoon (29.33 Nos. m^{-2}) which again corresponded positively with the biomass (20.77 g m^{-2}). The biomass was 0.98 g m^{-2} during monsoon and 0.51 g m^{-2} during the winter season at 10-20 cm soil layer

The fallow ecosystem also recorded the highest density of the species in the monsoon season with 90.44 Nos. m^{-2}, followed by pre-monsoon season with 48.88 Nos. m^{-2} and winter with 17.21Nos. m^{-2} respectively. The 0-10 cm soil depth also showed similar recordings for both density and biomass with the maximum in the monsoon (88 Nos. m^{-2} and 61.36 g m^{-2}), followed by pre-monsoon (48.88 Nos. m^{-2} and 37.21 g m^{-2}) and winter (14.77 Nos. m^{-2} and 3.04 g m^{-2}). No *Drawida* sp. was recorded in the pre-monsoon season but winter and monsoon seasons recorded 2.44 Nos. m^{-2} of the species at 10-20 cm soil layer with higher biomass in winter 0.81 g m^{-2} which was followed by monsoon (0.49 g m^{-2}).

In the plantation ecosystem also, the highest density of *Drawida* sp. was recorded in the monsoon season with 48.88 Nos. m^{-2} followed by pre-monsoon with 47.66 Nos. m^{-2} and winter with 13.44 Nos. m^{-2} respectively. In the 0-10 cm layer, maximum density and biomass records were recorded in the monsoon season (47.66 Nos. m^{-2} and 27.07 g m^{-2}), followed by pre-monsoon (40.66 Nos. m^{-2} and 22.95 g m^{-2}) and winter (13.44 Nos. m^{-2} and 7.42 g m^{-2}) respectively. However, at 10-20 cm layer, highest density and biomass count was recorded in the pre-monsoon season (7.33 Nos. m^{-2} and 5.78 g m^{-2}) with no record of the species in the winter season. Further, monsoon season amassed only 0.27 g m^{-2} of biomass.

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Table 26: Seasonal variation in density (Nos.m^{-2}) and biomass (g m^{-2}) of *Drawida* sp.in different sites.

Season	soil layers (cm)				Total	
	0-10		10-20		Density	Biomass
	Density	Biomass	Density	Biomass		
Winter	29.33±3.03	11.31±2.15	1.22±0.30	0.51±0.12	30.55±3.33	11.82±2.12
Pre-monsoon	46.44±3.17	43.76±3.34	13.44±2.62	20.77±3.09	59.88±5.79	64.53±6.43
Monsoon	59.88±4.45	76.96±7.01	1.22±0.30	0.98±0.24	61.10±4.75	77.94±7.25
Annual	135.66±2.10	132.04±3.15	15.88±0.90	22.28±1.17	151.54±3	154.32±4.32

a) Reserve forest ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20		Density	Biomass
	Density	Biomass	Density	Biomass		
Winter	14.77±1.34	3.04±0.38	2.44±0.35	0.81±0.11	17.21±1.69	3.85±.49
Pre-monsoon	48.88±4.26	37.21±4.77	0	0	48.88±4.26	37.21±4.77
Monsoon	88.00±4.34	61.36±4.20	2.44±0.35	0.49±0.08	90.44±4.69	61.85±4.28
Annual	151.66±2.93	101.62±2.63	4.88±0.17	1.30±0.04	156.54±3.10	102.92±2.67

b) Fallow land ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20		Density	Biomass
	Density	Biomass	Density	Biomass		
Winter	13.44±1.25	7.42±1.01	0	0	13.44±1.25	7.42±1.01
Pre-monsoon	40.33±0.58	22.95±2.20	5.78±1.11	6.59±0.09	47.66±2.03	28.73±3.31
Monsoon	47.66±7.33	27.07±4.88	0.27±0.06	0.51±0.12	48.88±7.63	27.34±4.94
Annual	101.44±2.44	57.47±1.76	6.06±0.39	11.16±0.47	109.99±2.94	63.53±2.15

c) Plantation ecosystem

Monthly variation of *Drawida* sp.

Monthly population density and biomass variations of *Drawida* sp. in the reserve forest exhibited peak in May (24.44 Nos. m^{-2}) and August (37.45 g m^{-2}) respectively. August (23.22 Nos. m^{-2}) also showed high presence of the species. The highest collection of density and biomass in the month of September (33 Nos. m^{-2} and 21.28 g m^{-2}) and (35.44 Nos. m^{-2} and 25.27 g m^{-2}) was accounted for both plantation and fallow sites respectively (**Figure 18 a and b**).

In the reserve forest area, the *Drawida* sp. population and biomass at 0-10 cm soil depth showed the maximum in the month of August (23.22 Nos. m^{-2} and 37.45 g m^{-2}). The density ranged from 4.89 Nos. m^{-2} (March) to 23.22 Nos. m^{-2} (August) and 1.22 Nos. m^{-2} (February) to 11 Nos. m^{-2} (May) at 0-10 cm and 10-20 cm soil layer respectively. The species could not be recorded in December at 0-10 cm soil layer. At the 10-20 cm soil depth the maximum biomass was in May (12.23 g m^{-2}).

In the fallow ecosystem, *Drawida* sp. population and biomass at 0-10 cm soil depth exhibited variations and recorded the highest count in September (34.22 Nos. m^{-2} and 24.90 g m^{-2}). The 10-20 cm soil layers recorded 1.22 Nos. m^{-2} of the species in November, December, September and October but amassed the highest biomass in December (.44 g m^{-2}).

In the plantation site, *Drawida* sp. population was mostly concentrated at 0-10 cm soil depth with the maximum and minimum ranging from 33 Nos. m^{-2} (September) and 2.44 Nos. m^{-2} (August). Biomass of the species also showed maximum count in September (21.28 g m^{-2}) with no collection in December in the same layer. At 10-20 cm soil depth only three months recorded *Drawida* sp. individuals with the maximum in June (6.66 Nos. m^{-2}) but May recorded the highest biomass with 4.72 g m^{-2}.

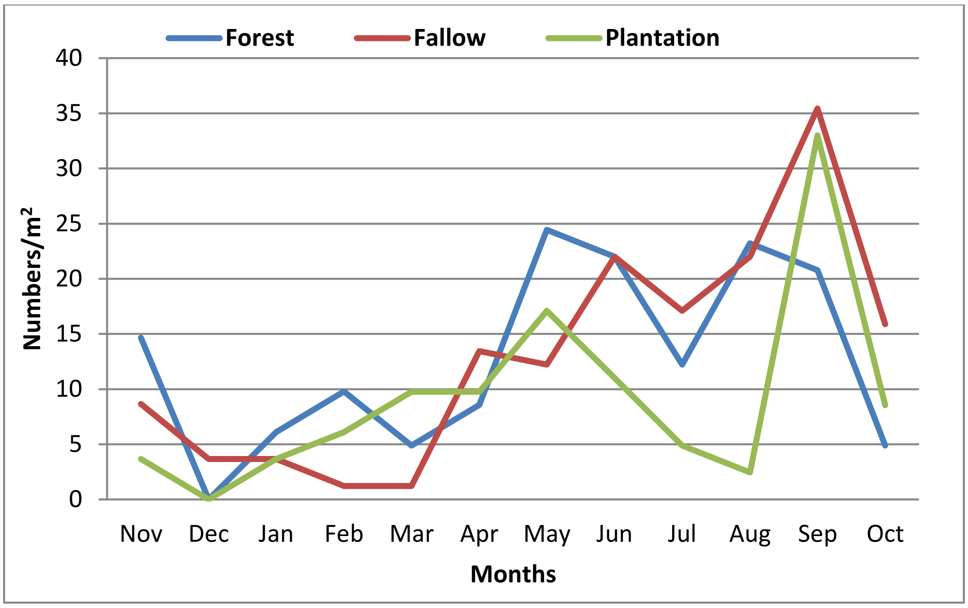

Figure 17 (a): Monthly variation of population density of *Drawida* sp. in different sites (Nos. m^{-2}).

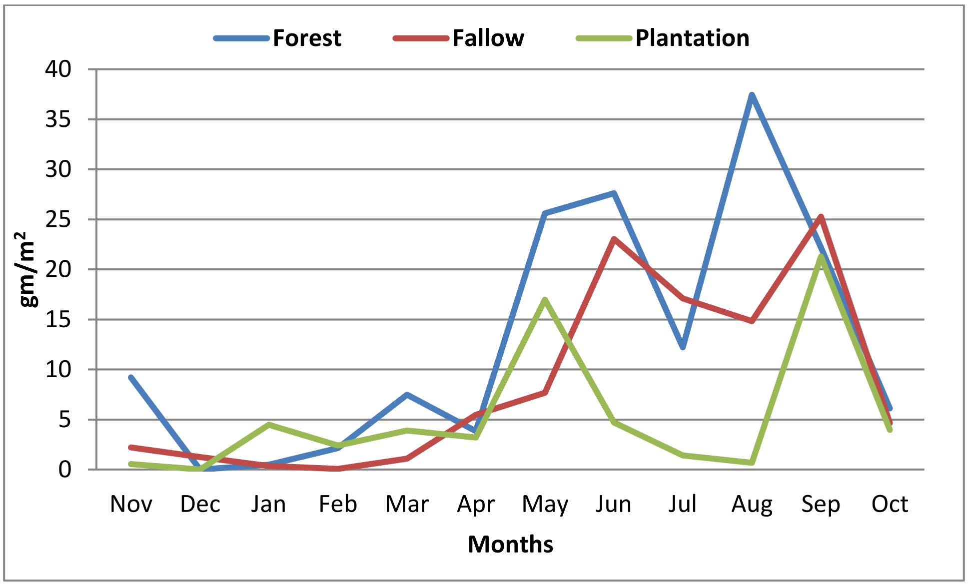

Figure 17 (b): Monthly variation of biomass of *Drawida* sp. in different sites (g m^{-2}).

ANOVA for population density

The ANOVA of *Drawida* sp. population (representing anecic) in the reserve forest (**Table 27**) did not show significant differences between the months of winter, pre-monsoon and monsoon seasons but exhibited significant differences between the months of annual ($F= 4.47$, $P < 0.05$) at 0-10 cm soil layer Even in the 10-20 cm layer, ANOVA showed significant differences between the months of annual ($F= 7.34$, $P < 0.01$) with no significant differences in any of the remaining seasons.

In the fallow land, the ANOVA of *Drawida* sp. showed significant variation between the months of monsoon ($F= 11.79$, $P < 0.05$) and annual ($F= 2.31$, $P < 0.05$) at 0-10 cm soil layer. While there was no result in the remaining seasons at 0-10 cm soil layer, no significant variation could be shown between the months of any seasons (**Table 28**) at 10-20 cm layer.

Analysis of variance (ANOVA) of *Drawida* sp. population in the plantation ecosystem showed significant variation between the months of pre-monsoon ($F= 8.14$, $P < 0.05$) and annual ($F= 2.39$, $P < 0.05$) at 0-10 cm soil layer (**Table 29**). However, no significant variation was exhibited between the months of winter ($F= 0.21$, $P > 0.05$) and monsoon ($F= 1.49$, $P > 0.05$) in the same layer. Similarly it also showed significant differences between the months of pre-monsoon ($F= 9.74$, $P < 0.05$) and annual ($F= 3.57$, $P < 0.05$) only at 10-20 cm layer.

Table 27: Analysis of variance (ANOVA) of *Drawida* sp. in the forest ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	10	1129.26	112.92	**	**
		Within the months	1	0.00	0.00		
		Total	11	1129.26			
	Pre-monsoon	Between the months	10	630.40	63.04	9.36	> 0.05
		Within the months	1	6.73	6.73		
		Total	11	637.14			
	Monsoon	Between the months	9	1697.16	188.57	1.13	> 0.05
		Within the months	2	331.45	165.72		
		Total	11	2028.61			
	Annual	Between the months	30	9781.16	326.03	4.47	< 0.05
		Within the months	5	365.12	73.02		
		Total	35	4146.28			
10-20	Winter	Between the months	8	5.58	0.69	0.31	> 0.05
		Within the months	3	6.69	2.23		
		Total	11	12.27			
	Pre-monsoon	Between the months	11	307.89	27.99	**	**
		Within the months	0	0.00			
		Total	11	307.89			
	Monsoon	Between the months	8	5.58	0.69	0.31	> 0.05
		Within the months	3	6.69	2.23		
		Total	11	12.27			
	Annual	Between the months	28	393.72	14.06	7.34	< 0.01
		Within the months	7	13.39	1.91		
		Total	35	407.12			

**: ANOVA showed no result.

Table 28: Analysis of variance (ANOVA) of *Drawida* sp.in the fallow land ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	8	200.51	25.06	**	**
		Within the months	3	0.00	0.00		
		Total	11	200.51			
	Pre-monsoon	Between the months	6	510.79	85.13	0.96	> 0.05
		Within the months	5	439.07	87.81		
		Total	11	949.87			
	Monsoon	Between the months	8	925.72	115.71	11.79	< 0.05
		Within the months	3	29.43	9.81		
		Total	11	955.15			
	Annual	Between the months	15	2599.42	173.29	2.31	< 0.05
		Within the months	20	1500.55	75.02		
		Total	35	4099.97			
10-20	Winter	Between the months	8	22.32	2.79	**	**
		Within the months	3	0.00	0.00		
		Total	11	22.32			
	Pre-monsoon	Between the months	8	NA	NA	**	**
		Within the months	3	NA	NA		
		Total	11	NA			
	Monsoon	Between the months	8	15.62	1.95	0.87	> 0.05
		Within the months	3	6.69	2.23		
		Total	11	22.32			
	Annual	Between the months	15	14.58	0.97	0.58	> 0.05
		Within the months	20	33.04	1.65		
		Total	35	47.62			

NA: ANOVA not computed since no earthworm was recorded.

**: ANOVA showed no result.

Table 29: Analysis of variance (ANOVA) of *Drawida* sp. in the plantation ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	8	133.27	16.65	0.21	> 0.05
		Within the months	3	228.49	76.16		
		Total	11	361.76			
	Pre-monsoon	Between the months	4	433.58	108.39	8.14	< 0.05
		Within the months	7	93.20	13.31		
		Total	11	526.78			
	Monsoon	Between the months	9	2400.23	266.69	1.49	> 0.05
		Within the months	2	356.41	178.20		
		Total	11	2756.64			
	Annual	Between the months	20	3511.03	175.55	2.39	< 0.05
		Within the months	15	1098.96	73.26		
		Total	35	4609.99			
10-20	Winter	Between the months	8	NA	NA	**	**
		Within the months	3	NA	NA		
		Total	11	NA			
	Pre-monsoon	Between the months	7	114.22	16.31	9.74	< 0.05
		Within the months	4	6.69	1.67		
		Total	11	120.92			
	Monsoon	Between the months	9	5.58	0.62	0.18	> 0.05
		Within the months	2	6.69	3.34		
		Total	11	12.27			
	Annual	Between the months	21	131.76	6.27	3.57	< 0.01
		Within the months	14	24.55	1.75		
		Total	35	156.32			

NA: ANOVA not computed since no earthworm was recorded.

**: ANOVA showed no result.

ANOVA for biomass

In the reserve forest, ANOVA of *Drawida* sp. biomass showed significant differences between the months of monsoon (F= 23.81, P < 0.05) and annual (F= 2.47, P < 0.05) at 0-10 cm soil layer (**Table 30**). However, in the 10-20 cm layer, it showed significant variation only between the months of annual (F= 4.63, P < 0.05).

In the fallow ecosystem, ANOVA of *Drawida* sp. biomass showed significant differences between the months of pre-monsoon (F= 7.08, P < 0.05) and annual (F= 2.59, P < 0.05) and no significant variation between the months of winter (F= 81.18, P > 0.05) and monsoon (F= 0.48, P > 0.05) at 0-10 cm soil layer (**Table 31**). At 10-20 cm soil layer, it showed significant difference only between the months of annual (F= 2.72, P < 0.05).

The ANOVA of the biomass in the plantation site, showed significant variation between the months of monsoon (F= 743.23, P < 0.01) and annual (F= 4.18, P < 0.05) at 0-10 cm soil layer while in the 10-20 cm soil layer, there was significant variation between the months of annual (F= 15.57, P < 0.01), no significant differences could be shown between the months of pre-monsoon (F= 11.32, P > 0.05) and monsoon (F= 0.47, P > 0.05). No result could be computed in the winter season in the same layer (**Table 32**).

Table 30: Analysis of variance (ANOVA) of biomass of *Drawida* sp. in the forest ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	10	566.10	56.61	22.16	> 0.05
		Within the months	1	2.55	2.55		
		Total	11	568.65			
	Pre-monsoon	Between the months	11	862.99	78.53	**	**
		Within the months	0	0.00			
		Total	11	862.99			
	Monsoon	Between the months	9	5983.03	664.78	23.81	< 0.05
		Within the months	2	55.83	27.91		
		Total	11	3668.87			
	Annual	Between the months	25	3733.93	149.32	2.47	< 0.05
		Within the months	10	603.73	60.37		
		Total	35	4336.93			
10-20	Winter	Between the months	10	2.17	0.21	**	**
		Within the months	1	0.00	0.00		
		Total	11	2.17			
	Pre-monsoon	Between the months	10	811.71	81.17	**	**
		Within the months	1	0.00	0.00		
		Total	11	811.71			
	Monsoon	Between the months	9	8.03	0.89	**	**
		Within the months	2	0.00	0.00		
		Total	11	8.03			
	Annual	Between the months	25	941.18	37.64	4.63	< 0.05
		Within the months	10	81.28	8.12		
		Total	35	1022.46			

**: ANOVA showed no result.

Table 31: Analysis of variance (ANOVA) of biomass of *Drawida* sp. in the fallow land ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	10	11.73	1.17	81.18	> 0.05
		Within the months	1	0.01	0.01		
		Total	11	11.74			
	Pre-monsoon	Between the months	7	1213.21	173.31	7.08	< 0.05
		Within the months	4	97.83	24.46		
		Total	11	1311.05			
	Monsoon	Between the months	6	647.76	107.96	0.48	> 0.05
		Within the months	5	1116.64	223.33		
		Total	11	1764.41			
	Annual	Between the months	15	2322.20	154.81	2.59	< 0.05
		Within the months	20	1195.24	59.65		
		Total	35	3517.45			
10-20	Winter	Between the months	8	2.48	0.31	**	**
		Within the months	3	0.00	0.00		
		Total	11	2.48			
	Pre-monsoon	Between the months	8	NA	NA	**	**
		Within the months	3	NA	NA		
		Total	11	NA			
	Monsoon	Between the months	4	0.25	0.06	0.48	> 0.05
		Within the months	7	0.93	0.13		
		Total	11	1.18			
	Annual	Between the months	14	3.16	0.22	2.72	< 0.05
		Within the months	21	1.75	0.08		
		Total	35	3.91			

NA: ANOVA not computed since no earthworm was recorded.

**: ANOVA showed no result.

Table 32: Analysis of variance (ANOVA) of biomass of *Drawida sp.* in the plantation ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	7	69.52	9.93	0.32	> 0.05
		Within the months	4	122.12	30.53		
		Total	11	191.65			
	Pre-monsoon	Between the months	6	191.92	31.98	0.77	> 0.05
		Within the months	5	205.65	41.13		
		Total	11	397.57			
	Monsoon	Between the months	9	1332.69	148.07	743.23	< 0.01
		Within the months	2	0.39	0.19		
		Total	11	1333.09			
	Annual	Between the months	12	752.44	62.70	4.18	< 0.05
		Within the months	23	344.94	14.99		
		Total	35	1097.38			
10-20	Winter	Between the months	7	NA	NA	**	**
		Within the months	4	NA	NA		
		Total	11	NA			
	Pre-monsoon	Between the months	9	90.99	10.11	11.32	> 0.05
		Within the months	2	1.78	0.89		
		Total	11	92.77			
	Monsoon	Between the months	7	0.27	0.03	0.47	> 0.05
		Within the months	4	0.32	0.08		
		Total	11	0.60			
	Annual	Between the months	13	98.64	7.58	15.57	< 0.01
		Within the months	22	10.71	0.48		
		Total	35	109.35			

**: ANOVA showed no result.

Annual population density and biomass of total earthworm

The annual population density and biomass of total earthworms with their vertical distribution in different soil layers of the reserved forest, plantation and fallow ecosystems is given in **Table 33 a, b and c.**

Of the three ecosystems, reserve forest recorded the highest earthworm population density (609.68 Nos. m^{-2}) followed by plantation (386.1 Nos. m^{-2}) and fallow (356.56 Nos. m^{-2}) ecosystem respectively. However, while maximum biomass too was recorded in reserve forest (549.87g m^{-2}), it was followed by fallow land (254.58 g m^{-2}) and plantation (216.60 g m^{-2}) respectively. As compared to reserve forest (site I), reduction of 41.52% density and 53.71 % biomass in the fallow ecosystem (site II) and reduction of 36.68 % density and 60.61 % biomass in the plantation ecosystem (site III) respectively was evident in the present study. There was a difference of 7.66 % and 14.92 % of density and biomass respectively between site II and site III. Collection of large size earthworms during monsoon season resulted in increasing biomass in the fallow area (site II). The location of the sampling plots in different altitudes along with variable physico-chemical factors of present study sites may play a limiting role in the abundance and biomass of earthworms (Kanchilakshmi and Thaddeus, 2016). The good canopy cover of reserve forest along with the thick presence of herbs, shrubs; and the least biotic disturbances maintains optimum condition for accumulation of soil nitrogen, organic carbon, moisture content and temperature; the condition of which is not found in other sites. Fire being strictly prohibited, the leave litters takes its own time to become humus which are favorable feeds for the earthworms. The fallow site is often visited by people for collecting fire woods and feeds for domestic animals, gardening and even hunting and trapping, thereby always subjected to sparse vegetation cover and biotic interference. Similarly, plantation site is often subjected to periodical pruning and clearing of the area which is actually intended to save and nurture the planted trees. In the process, the soil structure of these two sites is regularly disturbed which was evident from the lower record of different physico-chemical factors and high bulk density. Thus cumulative microclimatic features of soil ecosystem and topographic location might play an important role in differential distribution, density and biomass of the worms in the three study sites. In general the greater the intensity and frequency of degradation and disturbances in the natural forest, the lower is the population density and biomass of earthworms (Gerrard and Hay, 1979; Barnes and Ellis, 1979; Edwards, 1980; Satchell, 1983 Mackay and Kladivko, 1985; Haukka, 1988). In the various habitats of North Europe and North America, Lee (1985) observed that earthworm population hardly exceeded 400 m^{-2} but were found to be generally higher in forest or pastures than in the cultivated areas. Bhadauria *et al.* (2000) demonstrated the presence of highest earthworm population in the climax forest, followed by the mixed forest and the least count was in the mixed forest distressed by fire. Sharon *et al.* (2001) also reported that the abundance of the forest invertebrate was highly correlated with moisture and other microclimatic conditions. Kalu *et al*. (2015) reported that among different land use types, average earthworm population density (EPD) was found significantly higher in the forest than in agricultural land and grassland having shown the maximum population in the top layer (0-15 cm) of the soil.

The vertical distribution of the total earthworm density and biomass at 0-10 cm soil layer was 566.92 Nos. m^{-2} and 479.24 g^{-2} contributing 92.98 % and 87.15 % respectively to the total earthworms in reserve forest site. At 10-20 cm soil layer, density and biomass were 42.76 Nos. m^{-2} and 70.63 g m^{-2} contributing 7.01 % and 12.84% respectively to total earthworm population.

In the fallow ecosystem, earthworm density and biomass at 0-10 cm soil layer was 345.98 Nos. m^{-2} and 244.71 g m^{-2} contributing 96.91 % and 96.12% respectively to total earthworm. At 10-20 cm soil layer, density and biomass were recorded to be 10.98 Nos. m^{-2} (3.08%) and 9.87 g m^{-2} (3.87%) respectively.

In the plantation ecosystem, earthworm density and biomass at 0-10cm layer were 358.18 Nos. m^{-2} and 198.73 g^{-2} contributing 92.76 % and 91.74 % respectively to the total earthworm population. At 10-20 cm soil layer, density and biomass was 27.92 Nos. m^{-2} and 17.87 g m^{-2} g m^{-2} contributing 7.23 % and 8.25 % respectively to total earthworm population.

Table 33: Annual total number and biomass of total earthworm in different sites.

(A=percentage contributions to the total earthworm density in each soil layer respectively)

(B=percentage contributions to the total earthworm biomass in each soil layer respectively)

Density= (Numbers ± S.E. m^{-2}); Biomass= g m^{-2}

Soil layers	Forest		% contribution	
	Density	Biomass	Density	Biomass
	Nos.m^{-2}±S.E	g m^{-2}±S.E	A	B
0-10	566.92±24.47	479.24±18.67	92.98	87.15
10-20	42.76±2.69	70.63±3.89	7.01	12.84
Annual	609.68±11.33	549.87±9.05	100	100

a) Reserve forest ecosystem

Soil layers	Fallow		% contribution	
	Density	Biomass	Density	Biomass
	Nos.m^{-2}±S.E	g m^{-2}±S.E	A	B
0-10	345.98±15.97	244.71±8.81	96.91	96.12
10-20	10.98±.78	9.87±1.07	3.08	3.87
Annual	356.56±8.82	254.58±5.94	100	100

b) Fallow land ecosystem

Soil layers	Plantation		% contribution	
	Density	Biomass	Density	Biomass
	Nos.m^{-2}±S.E	g m^{-2}±S.E	A	B
0-10	358.18±24.42	198.73±14.13	92.76	91.74
10-20	24.43±1.83	17.87±1.66	7.23	8.25
Annual	386.1±9.33	216.6±5.33	100	100

c) Plantation ecosystem

Seasonal variation of density and biomass of total earthworm

The seasonal variation of density and biomass of total earthworms in the reserve forest, plantation and fallow ecosystems are shown in **Table 34 a, b and c**.

In the reserve forest ecosystem, the population density of total earthworms was more abundant in the monsoon season (257.71 Nos. m^{-2}) which was followed by the pre-monsoon (221.22 Nos. m^{-2}) and winter (130.76 Nos. m^{-2}) seasons. However, biomass recorded the maximum in pre-monsoon (239.33 g m^{-2}), followed by monsoon (224.04 g m^{-2}), and winter (77.62 g m^{-2}). Population density and biomass showed Monsoon>pre-monsoon>winter trend with maximum haul in monsoon (255.27 Nos. m^{-2} and 221.80 g m^{-2}) followed by pre-monsoon (184.57 Nos. m^{-2} and 175.52 g m^{-2}) and winter (127.1 Nos. m^{-2} and 73.05 g m^{-2}) seasons respectively at the 0-10 cm soil layer. Similarly, in the 10-20 cm soil layer, pre-monsoon recorded the highest density and biomass (36.65 Nos. m^{-2} and 63.81 g m^{-2}) followed by winter (3.66 Nos. m^{-2} and 4.57 g m^{-2}) and monsoon (2.44 Nos. m^{-2} and 2.24 g m^{-2}.) seasons.

A similar trend was observed even in the fallow ecosystem i.e. Monsoon>pre-monsoon>winter. Monsoon recorded the highest density and biomass count (173.48 Nos. m^{-2} and 138.24 g m^{-2}) which was followed by pre-monsoon (121.01 Nos. m^{-2} and 97.97 g m^{-2}) and winter (53.84 Nos. m^{-2} and 18.34 g m^{-2}) respectively. The 0-10 cm soil layer followed the same trend with the maximum during monsoon (171.04 Nos. m^{-2} and 137.75 g m^{-2}) and minimum during winter (50.18 Nos. m^{-2} and17.28 g m^{-2}). Interestingly, at 10-20 cm soil layer, highest density and biomass were collected during pre-monsoon (4.88 Nos. m^{-2} and 8.34 g m^{-2}) followed by winter (3.66 Nos. m^{-2} and 1.06 g m^{-2}) and monsoon (2.44 Nos. m^{-2} and .49 g m^{-2}).

In the plantation ecosystem also monsoon>pre-monsoon>winter trend was exhibited. Population density and biomass of total earthworm was maximum in monsoon (195.59 Nos. m^{-2} and 96.23 g m^{-2}) followed by pre-monsoon (139.27 Nos. m^{-2} and 85.2 g m^{-2}) and winter (80.64 Nos. m^{-2} and 35.17 g m^{-2}) seasons. At 0-10 cm also, showed a similar trend with the highest record during monsoon (193.15 Nos. m^{-2} and 95.44 g m^{-2}) followed by pre-monsoon (123.38 Nos. m^{-2} and 72.61 g m^{-2}) and winter (74.53 Nos. m^{-2} and 30.67 g m^{-2}) seasons respectively. However, at 10-20 cm soil depth, maximum total earthworms density and biomass were recorded during pre-monsoon (15.89 Nos. m^{-2} and 12.59 g m^{-2}) followed by winter (6.11 Nos. m^{-2} and 4.5 g m^{-2}) and monsoon (2.44 Nos. m^{-2} and 2.71 g m^{-2}) seasons.

Table 34: Seasonal variation in density ($Nos.m^{-2}$) and biomass ($g\ m^{-2}$) of total earthworm in different sites.

Season	soil layers (cm)				Total	
	0-10		10-20		Density	Biomass
	Density	Biomass	Density	Biomass		
Winter	127.1±6.58	73.05±3.57	3.66±.24	4.57±.49	130.76±2.81	77.62±1.53
Pre-monsoon	184.57±9.10	175.52±7.29	36.65±2.52	63.81±3.72	221.22±3.92	239.33±3.43
Monsoon	255.27±9.51	221.80±9.08	2.44±.22	2.24±.20	257.71±4.87	224.04±4.31
Annual	566.92±24.47	479.24±18.67	42.76±2.69	70.63±3.89	609.68±11.33	549.87±8.92

a) Reserve forest ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20		Density	Biomass
	Density	Biomass	Density	Biomass		
Winter	50.18±3.28	17.28±1.10	3.66±.36	1.06±.11	53.84±1.27	18.34±.42
Pre-monsoon	116.13±7.82	89.63±5.96	4.88±.45	8.34±1.05	121.01±3.01	97.97±2.26
Monsoon	171.04±22.46	137.75±8.59	2.44±.34	.49±.07	173.48±4.54	138.24±3.34
Annual	345.98±22.68	244.71±14.90	10.98±.78	2.84±1.07	356.96±8.82	254.58±5.83

b) Fallow land ecosystem

Season	soil layers (cm)				Total	
	0-10		10-20		Density	Biomass
	Density	Biomass	Density	Biomass		
Winter	74.53±5.68	30.67±2.57	6.11±.51	4.5±.57	80.64±2.10	35.17±.92
Pre-monsoon	123.38±8.74	72.61±5.09	15.89±1.31	12.59±1.13	139.27±3.30	85.2±1.90
Monsoon	193.15±14.27	95.44±6.69	2.44±.22	2.71±.07	195.59±5.36	96.23±2.50
Annual	391.06±28.38	198.73±14.13	24.43±1.83	17.87±1.66	415.58±10.65	216.6±5.23

c) Plantation ecosystem

Monthly variation of total earthworm

Monthly fluctuations of total earthworm population density and biomass exhibited variation in all the three sites as indicated in **Figure 19 a and b.**

With an initial number of 37.88 Nos. m^{-2} in November, population density in the reserve forest ecosystem exhibited fluctuating trend to reach the initial peak during May (72.1 Nos. m^{-2}) and thereafter attained the maximum during September (88 Nos. m^{-2}). At 0-10 cm layer minimum and maximum population ranged from 22.00 Nos. m^{-2} (December) to 88 Nos. m^{-2} (September); and at 10-20 cm from 1.22 Nos. m^{-2} (November, December, February and March) to 19.55 Nos. m^{-2} (May) respectively having no record during January, July, August and September. Similarly, total biomass varied from 12.01 g m^{-2} (December) to 112.58 g m^{-2} (May). Vertically minimum and maximum biomass ranged from December (11.54 g m^{-2}) to May (76.83 g m^{-2}) at 0-10 cm layer, and December (0.47 g m^{-2}) to May (35.75 g m^{-2}) at 10-20 cm layer.

In the fallow ecosystem, total earthworm population varied from January (6.1 Nos. m^{-2}) to September (64.76 Nos. m^{-2}) indicating two peak months i.e. June (43.98 Nos. m^{-2}) and September; while biomass fluctuated between 1.21 g m^{-2} (January) and 60.72 g m^{-2} (September). At 0-10 cm layer population density fluctuated exhibiting minimum during January (6.1 Nos. m^{-2}) and maximum September (63.54 Nos. m^{-2}). At 10-20 cm soil layer, minimum and maximum density varied from 1.22 Nos. m^{-2} of (September, October and December) to 2.44 Nos. m^{-2} (November, May and June) having no record in the months of January, February, March, April, July and August. Biomass was recorded maximum during June (7.54 g m^{-2}).

In the plantation ecosystem, population density fluctuated from November (13.43 Nos.m^{-2}) to August (57.54 Nos.m^{-2}). At 0-10 cm layer also minimum and maximum population ranged from 13.43 m^{-2} (November) to 57.43 m^{-2} (August); and at 10-20 cm from March (1.22 Nos.m^{-2}) to May (11 Nos.m^{-2}) respectively, having no record during November, January, February, April, July, August and September in lower strata. Total biomass ranged from 4.89 g m^{-2}) to 32.64 g m^{-2} (September). Vertically minimum and maximum biomass at 0-10 cm layer was recorded in February (4.89 g m^{-2}) and September (32.64 g m^{-2}) respectively and at 10-20 cm maximum biomass was recorded in May (9.35 g m^{-2}).

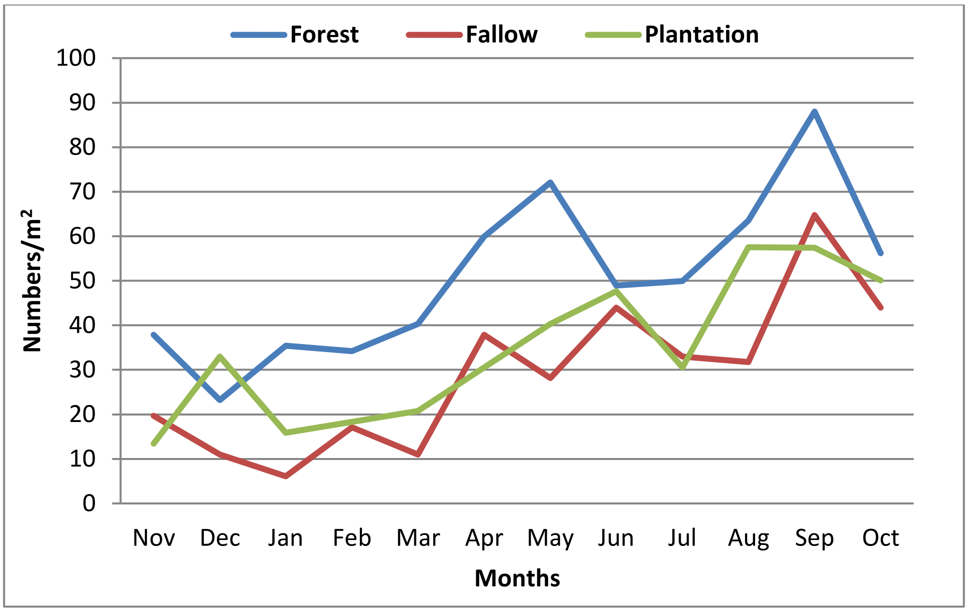

Figure 18 (a): Monthly variation of population density of total earthworm in different sites (Nos. m^{-2}).

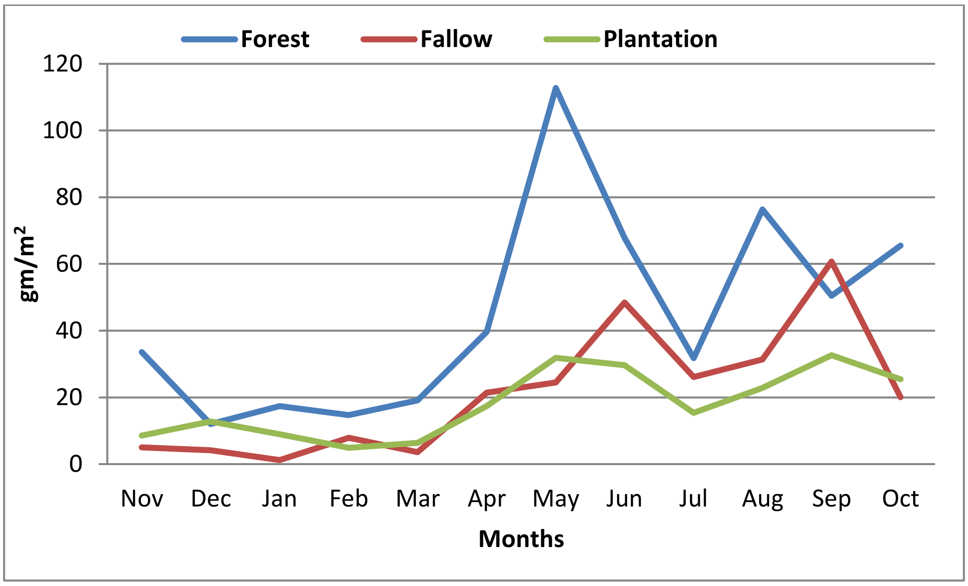

Figure 18 (b): Monthly variation of biomass of total earthworm in different sites (g m^{-2}).

ANOVA for total population density

The ANOVA of total earthworm population in the reserve forest (**Table 35**) showed significant differences between the months of monsoon (F= 23.545, P < 0.05) and annual (F= 5.33, P < 0.05) at 0-10 cm soil layer but not between the months of winter (F= 2.93, P > 0.05) and pre-monsoon (F= 11.98, P > 0.05) .In the 10-20 cm layer there was significant variation between the months of annual (F= 19.24, P < 0.01) but not in winter (F= 0.34, P > 0.05) and monsoon (F = 0.87, P > 0.05).

In the fallow ecosystem, the ANOVA of total earthworm population showed significant differences between the months of winter (F= 7.48, P < 0.05) and annual (F= 8.00, P < 0.01) at 0-10 cm layer. No significant variations were shown between the months of pre-monsoon (F= 0.36, P > 0.05) and monsoon (F= 0.40, P > 0.05) at 0-10 cm soil layers. At 10-20 cm layer, between the months of pre-monsoon (F= 0.35, P > 0.05) and annual (F= 1.08, P > 0.05) no significant difference was exhibited **(Table 36).**

In the plantation ecosystem, ANOVA of total earthworm population showed significant differences between the months of winter (F= 10.07, P < 0.05), pre-monsoon (F= 9.10, P < 0.05), monsoon (F= 5.77, P < 0.05) and annual (F= 2.25, P < 0.05) at 0-10 cm soil layer (**Table 37**). At the 10-20 cm soil layer, it exhibited significant differences between the months of winter (F= 10.97, P < 0.05) and annual (F= 3.23, P < 0.05).However no significant variation was exhibited between the months of pre-monsoon (F= 0.28, P > 0.05) and monsoon (F= 0.56, P > 0.05).

Table 35: Analysis of variance (ANOVA) of total earthworms in the forest ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	10	63.83	6.38	2.93	> 0.05
		Within the months	1	2.18	2.18		
		Total	11	66.02			
	Pre-monsoon	Between the months	10	66.06	6.60	11.98	> 0.05
		Within the months	1	0.55	0.55		
		Total	11	66.61			
	Monsoon	Between the months	9	1176.99	131.11	23.54	< 0.05
		Within the months	2	11.13	5.56		
		Total	11	188.13			
	Annual	Between the months	30	448.03	14.93	5.33	< 0.05
		Within the months	5	14.01	2.82		
		Total	35	462.04			
10-20	Winter	Between the months	8	0.29	0.03	0.34	> 0.05
		Within the months	3	0.31	0.10		
		Total	11	0.60			
	Pre-monsoon	Between the months	11	34.72	3.15	**	**
		Within the months	0	0.00			
		Total	11	34.72			
	Monsoon	Between the months	8	0.31	0.03	0.87	> 0.05
		Within the months	3	0.13	0.04		
		Total	11	0.45			
	Annual	Between the months	28	45.10	1.61	19.24	< 0.01
		Within the months	7	0.58	0.08		
		Total	35	45.69			

**: ANOVA showed no result.

Table 36: Analysis of variance (ANOVA) of total earthworms in the fallow land ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	7	23.32	3.33	7.48	< 0.05
		Within the months	4	1.77	0.44		
		Total	11	25.10			
	Pre-monsoon	Between the months	6	18.15	3.02	0.36	> 0.05
		Within the months	5	41.94	8.39		
		Total	11	60.10			
	Monsoon	Between the months	9	42.88	4.76	0.40	> 0.05
		Within the months	2	23.73	11.87		
		Total	11	66.62			
	Annual	Between the months	21	1065.16	50.72	8.00	< 0.01
		Within the months	14	88.72	6.33		
		Total	35	1153.89			
10-20	Winter	Between the months	8	1.50	0.18	**	**
		Within the months	3	0.00	0.00		
		Total	11	1.50			
	Pre-monsoon	Between the months	7	0.61	0.08	0.35	> 0.05
		Within the months	4	0.99	0.24		
		Total	11	1.60			
	Monsoon	Between the months	10	0.45	0.04	**	**
		Within the months	1	0.00	0.00		
		Total	11	0.45			
	Annual	Between the months	21	2.24	0.10	1.08	> 0.05
		Within the months	14	1.37	0.09		
		Total	35	3.62			

**: ANOVA showed no result.

Table 37: Analysis of variance (ANOVA) of total earthworms in the plantation ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	8	36.90	4.61	10.07	< 0.05
		Within the months	3	1.37	0.45		
		Total	11	38.27			
	Pre-monsoon	Between the months	7	66.30	9.47	9.10	< 0.05
		Within the months	4	4.16	1.01		
		Total	11	70.46			
	Monsoon	Between the months	6	119.02	19.83	5.77	< 0.05
		Within the months	5	17.18	3.43		
		Total	11	136.21			
	Annual	Between the months	15	213.94	14.26	2.25	< 0.05
		Within the months	20	126.60	6.33		
		Total	35	340.54			
10-20	Winter	Between the months	8	3.95	0.49	10.97	< 0.05
		Within the months	3	0.13	0.04		
		Total	11	4.09			
	Pre-monsoon	Between the months	9	5.03	0.55	0.28	> 0.05
		Within the months	2	3.97	1.98		
		Total	11	9.00			
	Monsoon	Between the months	8	0.27	0.03	0.56	> 0.05
		Within the months	3	0.18	0.06		
		Total	11	0.45			
	Annual	Between the months	14	17.08	1.22	3.23	< 0.05
		Within the months	21	7.92	0.37		
		Total	35	25.01			

ANOVA for biomass

The ANOVA for total earthworm biomass in the reserve forest (**Table 38**) showed significant differences between the months of pre-monsoon (F= 450.37, P < 0.05), monsoon (F= 22.16, P < 0.05) and annual (F= 4.87, P < 0.05) at 0-10 cm soil layer but not between the months of winter (F= 4.53, P > 0.05). In the 10-20 cm layer there was significant variation between the months of annual (F= 46.65, P < 0.01) but not in winter (F= 15.19, P > 0.05) and monsoon (F= 1.25, P > 0.05).

However in fallow ecosystem, ANOVA showed significant variation only between the months of monsoon (F= 291.35, P < 0.05) and annual (F= 3.71, P < 0.05) at 0-10 cm soil layer (**Table 39**). It did not show significant variation between the months of winter (F= 1.99, P > 0.05). At the 10-20 cm soil layer, no significant variation was observed between the months of winter (F= 0.55, P > 0.05) and pre-monsoon (F= 15.41, P > 0.05), but showed significant variation between the months of monsoon (F= 166.76, P < 0.05) and annual (F= 38.10, P < 0.05).

In the plantation ecosystem, ANOVA of total earthworm biomass showed significant differences between the months of pre-monsoon (F= 10.73, P < 0.01), monsoon (F= 5.19, P < 0.05) and annual (F= 4.06, P < 0.05) at 0-10 cm soil layer (**Table 40**). At the 10-20 cm soil layer, it exhibited significant differences between the months of winter (F= 278.93, P < 0.05) and annual (F= 5.89, P < 0.05).However no significant variation was exhibited between the months of pre-monsoon (F= 0.21, P > 0.05) and monsoon (F= 0.22, P > 0.05).

Table 38: Analysis of variance (ANOVA) of biomass of total earthworms in the forest ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	10	69.37	6.93	4.53	> 0.05
		Within the months	1	1.53	1.53		
		Total	11	70.91			
	Pre-monsoon	Between the months	10	140.74	14.07	450.37	< 0.05
		Within the months	1	0.03	0.03		
		Total	11	140.77			
	Monsoon	Between the months	9	672.01	74.66	22.16	< 0.05
		Within the months	2	7.27	3.36		
		Total	11	679.29			
	Annual	Between the months	30	612.18	20.40	4.87	< 0.05
		Within the months	5	20.92	4.18		
		Total	35	633.10			
10-20	Winter	Between the months	8	2.06	0.25	15.19	< 0.05
		Within the months	3	0.05	0.01		
		Total	11	2.11			
	Pre-monsoon	Between the months	11	104.01	9.45	**	**
		Within the months	0	0.00			
		Total	11	104.01			
	Monsoon	Between the months	8	0.29	0.03	1.25	> 0.05
		Within the months	3	0.08	0.02		
		Total	11	0.38			
	Annual	Between the months	28	142.99	5.10	46.65	< 0.01
		Within the months	7	0.76	0.10		
		Total	35	143.75			

**: ANOVA showed no result.

Table 39: Analysis of variance (ANOVA) of biomass of total earthworms in the fallow land ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	10	4.34	0.43	1.99	> 0.05
		Within the months	1	0.21	0.21		
		Total	11	4.56			
	Pre-monsoon	Between the months	11	60.01	5.45	**	**
		Within the months	0	0.00			
		Total	11	60.01			
	Monsoon	Between the months	10	4903.58	490.35	291.35	< 0.05
		Within the months	1	1.68	1.68		
		Total	11	111.27			
	Annual	Between the months	26	446.93	17.18	3.71	< 0.05
		Within the months	9	41.64	4.62		
		Total	35	288.58			
10-20	Winter	Between the months	8	0.05	0.00	0.55	> 0.05
		Within the months	3	0.03	0.01		
		Total	11	0.08			
	Pre-monsoon	Between the months	10	8.39	0.83	15.41	> 0.05
		Within the months	1	0.05	0.05		
		Total	11	8.44			
	Monsoon	Between the months	9	12.00	1.33	166.76	< 0.05
		Within the months	2	0.01	0.00		
		Total	11	0.02			
	Annual	Between the months	22	8.99	0.40	38.10	< 0.05
		Within the months	13	0.14	0.01		
		Total	35	9.13			

**: ANOVA showed no result.

Table 40: Analysis of variance (ANOVA) of biomass of total earthworms in the plantation ecosystem at 0-10 and 10-20 cm soil layers.

Soil layers(cm)	Seasons	Source of variation	df	SS	MS	F	Sig.(P)
0-10	Winter	Between the months	8	3.58	0.44	0.23	> 0.05
		Within the months	3	5.72	1.91		
		Total	11	9.31			
	Pre-monsoon	Between the months	7	75.82	10.83	10.73	< 0.01
		Within the months	4	4.03	1.00		
		Total	11	79.86			
	Monsoon	Between the months	6	141.29	23.54	5.19	< 0.05
		Within the months	5	22.67	4.53		
		Total	11	163.97			
	Annual	Between the months	15	77.47	5.16	4.06	< 0.05
		Within the months	20	25.42	1.27		
		Total	35	142.89			
10-20	Winter	Between the months	8	3.01	0.37	278.93	< 0.05
		Within the months	3	0.00	0.00		
		Total	11	3.01			
	Pre-monsoon	Between the months	9	3.60	0.40	0.21	> 0.05
		Within the months	2	3.72	1.86		
		Total	11	7.32			
	Monsoon	Between the months	8	0.01	0.00	0.22	> 0.05
		Within the months	3	0.03	0.01		
		Total	11	0.05			
	Annual	Between the months	14	25.00	1.78	5.89	< 0.05
		Within the months	21	6.35	0.30		
		Total	35	11.36			

The varied presence of earthworms in three different sites and seasons is generally influenced by a combination of many ecological parameters of which the two major factors are soil temperature and moisture (Reynolds and Jordan, 1975; Edward, 2004) and lack of moisture causes earthworms to diapause thus affecting their activity (Gerard,1960). Soil moisture content was found to be the most vital regulating factor for the fluctuating pattern of earthworm population density (Evans and Guild, 1947). Dash and Patra (1977) and Kale and Krishnamoorthy (1978, 1982) also recorded the maximum earthworm density and biomass in the rainy or late rainy period. The investigation indicated that the earthworm population increased during the warm humid to rainy season having a declining tendency with approaching winter. The soil moisture content ranging from 13.85 to 42.02 % in the fallow and plantation sites resulted in a decrease in the earthworm population while in the reserve forest site, higher range of soil moisture between 26.72 % and 64.14 % (even above 40% during winter) supported a fairly good number of earthworm population.

Population distribution is significantly affected by the soil temperature because the activity, metabolism, growth and reproduction of earthworm are all influenced by temperature. It is also observed that high surface temperature and dry soils are much more limiting to the earthworms than low temperature and waterlogged soils. In the present investigation, the peak population density of earthworm in relation to the maximum range of soil temperature of 19ºC to 25ºC was found to be more or less within the optimal temperature range of 20ºC to 30ºC for tropical and sub-tropical species (Lee, 1985; Edwards and Bohlen, 1996). Further, monthly fluctuation of soil temperature shows a distinct fluctuation pattern with a gradual decrease of temperature as winter approaches and subsequent increase in the temperature with the onset of pre-monsoon and monsoon season. Timmerman *et al*. (2006) also reported low earthworm abundance all through winter due to the low temperature. In contrast, Kaushal *et al*. (1995) did not observe any earthworms starting from the second half of January through February when soil temperature was very low (4.8 ºC - 6.2 ºC). Gerard (1967) also made similar observation stating that earthworms become inactive during the dry periods wherein the worms burrow deeper into the soil layers. Lavelle *et al*. (1989) also stated that soil temperature is one of the important edaphic factors which influence the structure, composition and abundance of earthworm populations. Whalen *et al*. (1998) also reported that a significant decline in abundance of earthworms in summer can be attributed to changes in soil temperature as well as moisture. It can thus be concluded that temperature and moisture work synergistically to influence the earthworm population. According to Hand (1988), a temperature of 20ºC to 25ºC and moisture of 50–60 percent is most favorable for earthworm activity. Further, the minimal rainfall, comparatively high temperature and fairly low humidity during the months of February, March and April have a negative impact on the total earthworm population especially in the fallow site which recorded the least worm population among the three sites.

The increased activity of earthworm resulting maximum population density during the rainy season is due to the favorable soil moisture content, temperature and humidity (Gerard, 1960; Edwards and Lofty, 1972). The monsoon tropical and humid climate of India facilitates earthworm activity mainly from May to October i.e. the 4-6 months of the rainy season (Gate, 1961). Reports from various parts of the world including India at different times highlighting the pattern of changes in earthworm population density and biomass vis-à-vis seasonal variation particularly high abundance during monsoon season conform the present findings (Lavelle, 1973; Dash and Senapati,1980; Rozen, 1982; Julka (1986 a, b;Valle *et al*., 1997; Mishra and Dash,1984; Mohanjit, 1986; Julka and Paliwal,1989; Bhadauria and Ramakrishnan, 1989, 1991; McCredie *et al.*,1992; Kaushal *et* *al*., 1995, 1999; Blanchart and Julka,1997, Chaudhuri *et al.*, 2009). Reddy and Alfred (1978) recorded maximum and minimum density in July and April respectively in a pine forest of Meghalaya. The high earthworm population density and biomass during the moist season, has also been reported from seasonal tropical forests (Nemeth and Herrera, 1982), savannahs of Lamto (Lavelle, 1984) and tropical forest of Chajul (Fragoso and Lavelle, 1992). Mishra and Ramakrishnan (1988) also reported a decline in the population density with the approach of winter from November to March and observed two major peaks during May-June and September-October respectively, which supports the present findings. Araujo and Hernandez (1999) also demonstrated the significance of soil moisture content in influencing earthworm distribution and activity. Bisht *et al.* (2003) reported that the seasonal dynamics over an annual cycle showed that the earthworm population and biomass were high in wet period and low during summer and winter that related to high reproduction and endurance level due to the presence of higher moisture in the soil. Chaudhari *et al.* (2008) reported two peak periods of population structure in May-June and September-October from sub-tropical deciduous rubber plantation forest Tripura. Joshi and Aga (2009) showed a higher number of species count during the rainy season in comparison to early winter and summer. Lalthazara *et al.* (2011) from Mizoram recorded the peak period of earthworm abundance during monsoon season i.e. May-September which coincided with high range of soil moisture and temperature. Haokip and Singh (2012) observed that the highest population of earthworm during the rainy season was linked to the maximum moisture content in that season and gradually decreased during summer and winter season. Bhadauria *et al.* (2012) also reported maximum population density and biomass earthworm population during the rainy season and subsequent shrinking between September (end of rainy season) and November (beginning of winter) in a traditional pure crop system and traditional agroforestry systems due to soil moisture content which is the prime importance for the survival, sustenance and increase of earthworms in any habitats.

In the present investigation epigeic, endogeic and anecic species were found to be highest during the months of monsoon season as compared to early winter and pre-monsoon season. *Perionyx* sp. was the most dominant species among the epigeic species followed by *Amynthas corticis* and *Amynthas* sp.1. *Amynthas corticis* was found in the plantation site only during the winter season; however, it was recorded throughout the year in reserve forest area having optimum moisture level ranging from 36.42 to 44.31%. *Perionyx* sp. was recorded maximum during September and October in reserve forest; during October in fallow land; and October and December in plantation area respectively due to congenial moisture of 12-25 % (Olson, 1928). Another epigeic species *Amynthas* sp.1 was not recorded at all in the three sites throughout the winter and pre-monsoon season, only showing its presence in the reserve forest after the onset of regular monsoon rainfall. *Eutyphoeus festivus* and *Eutyphoes* sp.no.1 were the dominant species among the endogeic group. Taking 0-20 soil layer, *Eutyphoeus festivus* was the most abundant earthworm species with 28.27 % and 46.87 % in the reserve forest (site I) and plantation (site III) ecosystems respectively while in fallow land (site II) the lone representative of anecic species i.e. *Drawida sp.* was the most abundant earthworm with 43.85 % which was followed by *Eutyphoeus festivus* contributing 33.35 % to the total earthworms. *Drawida sp.* was also found to be highest during the monsoon seasons in reserve forest, however, in fallow and plantation site, it reached the peak during May and least during winter and pre-monsoon season. In forest site (site I), at 0-10 cm soil layer, *Eutyphoeus festivus* recorded the highest number species-wise (27.85 %) which was followed by *Perionyx* sp. (27.02%) and *Drawida* sp. (23.96%). In site II, *Drawida* sp. was the most abundant earthworm species with 43.83 % followed by *Eutyphoeus festivus* (33.55 %) and

Perionyx sp. (10.24 %) at 0-10 cm soil layer. While in site III, *Eutyphoeus festivus* recorded the highest density (46.66 %) followed by *Drawida* sp. (27.84 %) and *Eutyphoeus* sp.no.1 with (17.10 %) at the 0-10 soil layer. It can be hence concluded that *Eutyphoeus festivus* was the most abundant species in the study site with its consistent presence.

Vertical distribution of earthworms showed a steep decline in population with an increase in soil depth having no record beyond 20 cm soil layer in all the three study sites. However, among the three sites, density and biomass of earthworm population were recorded maximum in reserve forest ecosystem both at 0-10 and 10-20 cm soil layers. Higher carbon and nitrogen content in the top layer may be one of the reasons for higher earthworm population density in present study sites. A decrease in the amount of soil oxygen with an increase of soil depth may limit the distribution of earthworms in deeper layer (Curry and Cotton, 1983). Though atmospheric temperature increases during the pre-monsoon period, the soil is normally very dry due to paucity of rainfall which in turn affects the soil moisture content in the ecosystem. Reddy and Pasha (1993) also showed that the lowest record of earthworms was during the summer season possibly due to the dry condition of the soil. In the present investigation, the soil moisture content in the top layer was found to be always higher than in the lower soil layers. During the monsoon season, sometimes due to continuous rainfall, the earthworms burrowed inside the soil with only very fewer worms found on the upper soil layer due to their inability to adjust to the flood like situation. Rainfall affects the relative humidity during the monsoon season and plays a vital role in the increase of soil moisture content thereby subsequently increase in earthworm population. Less rainfall resulted in declining moisture content in the soil during the winter and pre-monsoon seasons which could have been the most probable reason for the lesser presence of earthworms in the soil. The endogeic and anecic species of earthworm which are recorded minimum in 10-20 cm soil layer during winter are found curled inside a tight cocoon shaped ball, while epigeic species like *Amynthas sp.1* was totally absent in the fallow and plantation sites. Reddy (1983) and Fragoso and Lavelle (1992) also made a similar observation with earthworms being found only in the upper (0-10 cm) layer of the soil during the rainy season and infiltrating downwards into the deeper soil as winter approached. Dash (2013) reported that earthworms, in order to counter extreme temperature undergo diapauses to avoid water loss and also avoid desiccations which are significant adaptive mechanisms for survival. Total biomass contribution is also 87.15%, 96.12% and 91.74% at 0-10 cm soil layer in reserve, fallow and plantation respectively. Contrary to the present findings, Kooch *et al.* (2008) recorded an unusual record of higher density and biomass in the 20-30 cm soil depth from Hornbeam forest in Iran. In the Colorado and Palm forests, Borges and Alfaro (1997) observed higher biomass accumulation at 0-10 cm soil layer due to the presence of the giant earthworm *Trigaster longissimus.* Clapperton *et al.* (1997) have reported the presence of earthworm more or less exclusively in the top 50 cm layer of agricultural soil. Kaushal *et al. (*1999) recorded 84 to 88.4% and 93 to 97.7% of density and biomass respectively at 0-10 cm Kumaun Himalayan forest ecosystem. Bisht *et al.* (2003) also recorded maximum density and biomass of earthworm in the top layer of soil i.e. 0-10 cm from maize crop (83.7% and 80.9%), Paddy and pulse crop (100% of density and biomass each) and wheat and mustard crop (95.5% and 92.6%). Irannzed and Rahmani (2009) reported 88% of earthworm density and 82% of the biomass in the topsoil layer of 0-10 cm depth. In an agro-forestry system of Mizoram, Lalthanzara and Ramanujam (2014) recorded maximum density of earthworm at 0-10 cm (61.4%) which was followed by 10-20 cm (33.22%) and 20-30 cm (5.38%) layer. Prasad *et al*. (2016) also recorded a mean of 67.1% and 64.5% of density and biomass respectively at the 0-10 cm soil layer. Differences in the microclimatic condition of the soil combined with the different physico-chemical factors of the soil at 0-10 cm and 10-20 cm, and also the soil organic matter content appears to be key factors in the earthworm distribution.

Plate 9: ***Perionyx*** **sp.**

Plate 10: ***Eutyphoeus festivus***

Plate 11: ***Eutyphoeus*** **sp.no.1**

Plate 12: ***Eutyphoeus marmoreus***

Plate 13: ***Amynthas corticis***

Plate 14: ***Amynthas*** **sp. 1**

Plate 15: *Drawida* sp.

Chapter-VII

IMPACT OF PHYSICO-CHEMICAL FACTORS ON EARTHWORMS

Relationship with earthworm density

The three dominant species *Perionyx* sp., *Eutyphoeus festivus* and *Drawida* sp., each representing the three ecological types epigeic, endogeic and anecic categories respectively and total earthworm density, as well as their biomass were correlated with the different soil parameters using SPSS software. The results are shown in **Table 41-64**.

Effect of soil temperature

In the reserve forest ecosystem, the soil temperature showed a positive significant relationship with the population density of *Drawida* sp. ($r = 0.43$, $P < 0.01$) and *Eutyphoeus festivus* ($r = 0.39$, $P < 0.05$) at 0-10 cm soil layer (**Table 53 and 47)**. A similar trend was observed in the plantation site at 0-10 cm layer. Soil temperature did not show a positive relationship with *Perionyx* sp. in the same soil layer (**Table 41**) However, there was a positive significant relationship with the total earthworm density ($r = 0.49$, $P < 0.01$) at 0-10 cm soil layer (**Table 59**). It showed a similar trend in the plantation site at 0-10 cm layer and interestingly in the fallow site, the density of *Perionyx* sp. showed a positive correlation ($r = 0.44$, $P < 0.01$) with the temperature at the 0-10 cm layer (**Table 44**). In the 10-20 cm soil layer, soil temperature showed a negative relationship with some species and with some, it did not show any significant relationship following the trend of soil moisture in the study sites. In general, the total earthworm density exhibited significant positive correlation ship ($P < 0.01$) with temperature. The correlationship results in the present investigation showed that soil temperature is an important soil parameter having a positive impact on earthworm population density and is an essential factor which influences the structure, composition and abundance of earthworm population (Lavelle *et al*., 1989). Tiwari *et al*. (1992) found a significant correlation between earthworm population and edaphic factors like temperature and moisture in pineapple orchards of East Khasi Hills of North Eastern region of India.

Dash (2013) also highlighted that in Indian conditions earthworms function optimally between 0^{o}C and 30^{o}C; however, depending upon the moisture content their figures decline when the soil temperature is below 4^{o}C or above 25^{o}C.

Effect of soil moisture

The soil moisture content level was found to be higher in the topsoil layer than in the 10-20 cm soil layer in all the three study sites. Corresponding to this, the total earthworm population and also the different earthworm species decreased with increasing soil depths in all the three sites. It exhibited a high positive significant relationship with the population density of *Perionyx* sp. (r= 0.28, P < 0.05) and *Eutyphoeus festivus* (r= 0.24, P < 0.05), and total earthworms (r= 0.39, P < 0.05) in the reserve forest ecosystem (**Table 41, 47 and Table 59**). However, it showed no significant relationship with *Drawida* sp. in the same layer

In the fallow ecosystem, moisture content showed a very high positive significant relationship with the density of *Drawida* sp. (r = 0.76, P < 0.01) (**Table 53**) and total earthworm density (r= 0.68, P < 0.01) (**Table 61**). The soil moisture content also showed a positive significant relationship with *Perionyx* sp. (r= 0.28, P < 0.05) and *Eutyphoeus festivus* (r= 0.29, P < 0.05) in the same layer. (**Table 43 and 47**)

While in the plantation ecosystem, similar to the forest ecosystem, moisture content exhibited positive significant relationship with the density *Eutyphoeus festivus* (r= 0.31, P < 0.05), *Drawida* sp. (r= 0.31, P < 0.05) and total Earthworms (r= 0.39, P < 0.05) at 0-10 cm soil layer (**Table 51, 57 & 59**). But it did not show a positive relationship with *Perionyx* sp. in the same soil layer. At the 10-20 cm soil layers though, moisture content showed an insignificant or negative relationship with the density of the earthworm species. The trend point to the fact that with increasing depth in the soil, moisture content also decreases, resulting in a concentration of earthworms at the top layer. Total earthworms showed positive significant relationships with soil moisture content in all the three study sites viz. reserve forest (r = 0.39, P < 0.05), fallow (r = 0.68, P < 0.01) and plantation (r=0 .39, P < 0.05) respectively (**Table 59, 61 & 63**).

Ismail *et al.* (1990), Tiwari *et al*. (1992) and Joshi *et al.* (2010) reported a significant positive correlation between earthworm population density and soil moisture content. Araujo and Hernandez (1999) also showed the significance of soil moisture content in determining the distribution and activity of earthworm species.

Effect of bulk density

Soil dry bulk density is an indicator of soil compaction which can have a huge impact on earthworm abundance (Edwards, 2004). In the present investigation, the value of bulk density exhibited a significant negative relationship with *Drawida* sp. (r = -0.37, P < 0.05) and *Eutyphoeus festivus* (r = -0.33, P < 0.05) at 0-10 cm soil layer (**Table 53 & 57**) in the reserve forest ecosystem. The pattern was similar in both the plantation and fallow ecosystems. Even with total earthworm, bulk density showed significant negative correlationship in reserve forest (r = -0.50, P < 0.01), fallow (r = -0.47, P < 0.01) and plantation (r = -0.30, P < 0.05) at 0-10 cm soil layer. In the 10-20 cm soil layer also, it showed similar results, with a negative relationship or no significant relationship with almost all the earthworms. However, highest soil bulk density was observed in fallow land and plantation ecosystem in both soil layers which corresponded with low earthworm presence in the two sites as compared to the reserve forest ecosystem. Yeates *et al.* (1998) have observed that the effectiveness of bulk density, as well as soil porosity as indicators of earthworm abundance, is restricted only to particular soil types. Yeates *et al* (1998) and Bithell *et al.* (2005) also showed a high significant negative correlation with the earthworm populations.

Effect of soil pH

The soil pH showed an insignificant relationship with almost all the earthworm species and a negative significant relationship with certain earthworm species at the 0-10 cm soil layer. With the soil pH ranging from 4.5 to 6.23 in the present study site, earthworm species like *Perionyx* sp., *Amynthas* species, *Drawida* sp. and *Eutyphoeus* species are considered as acid soil tolerant species (Nath and Chaudhari, 2010). The insignificant relationship between soil pH and earthworm population density highlighted that earthworm dwell both in acidic as well as neutral soil (Baltzer, 1956). Nordstrom and Rundgren (1973, 1974) also reported that few earthworms in soils with pH below 4.5 with low as well as a high population of earthworms in sites between pH ranges of 4.5-6.6. Dash (2013) also observed that earthworms prefer a pH range of 6.5 to 7.5 but can also tolerate and perform bodily functions between pH 5-8 without much difficulty and that different species exhibit different pH tolerance within a range of 5-8 thereby influencing earthworm distribution. However, Paliwal and Julka (2005) reported that the majority of earthworm species prefers pH ranging between 7.4 and 7.8 (slightly alkaline).

Effect of available nitrogen

Available Nitrogen content showed a positive significant relationship with *Perionyx* sp. ($r = 0.29$, $P < 0.05$) and *Drawida* sp. ($r = 0.41$, $P < 0.05$) at 0-10 cm soil layers in the reserve forest ecosystem (**Table 42 & 54)**. Nitrogen content also showed positive significant relationship with total earthworm density ($r = 0.35$, $P < 0.05$, $r = 0.40$, $P < 0.05$, $r = 0.37$, $P < 0.05$) in the reserve forest, fallow and plantation ecosystems respectively (**Table 60, 62 & 64**). With *Eutyphoeus festivus*, at 0-10 cm soil layer nitrogen exhibited positive significant relationship in the plantation (r= 0.27, P < 0.05) (**Table 52**) and fallow (r= 0.39, P < 0.05) ecosystems (**Table 50**). This result shows that earthworms contribute to the mineralization of nitrogen in the soil. At 10-20 cm soil layers, it showed the negative significant relationship and insignificant relationship which could be easily understood from the very minimal record of earthworms in the soil layers.

In the present investigation, the reserve forest ecosystem with more nitrogen showed more diversity and density of earthworms than in the fallow and plantation ecosystem as earthworm tend to inhabit in soils with more nitrogen (Russell, 1950). Evans and Guild (1948) demonstrated that quick growth of earthworms is felicitated by nitrogen-rich diets which also help enhance increased production of cocoons in comparison to earthworms found in minimal nitrogen availability soils. The nitrogen availability in all the three sites showed consistency in their availability indicating good soil fertility throughout the year, at both soil layers (0-10 and 10-20 cm). Curry (2004) showed that the nitrogen content of organic matter reveals protein concentrations and is also a fine pointer to good food quality for earthworms. He also stated that nitrogen availability is often considered a vital dynamic limiting earthworm distribution. Similar observations were reported by Satchel (1967) and Lee (1983) in the temperate and tropical forests respectively.

Effect of soil phosphorous

The available phosphorus showed a positive significant relationship with *Perionyx* sp. (r= -0.28, P < 0.05) and *Drawida* sp. (r= -0.29, P < 0.05) at 0-10 cm soil layers in the reserve forest ecosystem (**Table 42 & 54**). However, it exhibited an insignificant relationship with *Eutyphoeus festivus*. In the fallow ecosystem, phosphorus showed positive significant relationship with *Perionyx* sp. (r= 0.28, P < 0.05), *Eutyphoeus festivus* (r= 0.27, P < 0.05) and *Drawida* sp. (r= 0.34, P < 0.05) at 0-10 cm soil layers (**Table 44, 49 & 56**). In the plantation ecosystem also, it showed a positive significant relationship with *Eutyphoeus festivus* (r= 0.28, P < 0.05) and *Drawida* sp. (r= 0.29, P < 0.05) at the 0-10 cm soil layers (**Table 52 & 58)**.

With the total earthworm density phosphorus did not show any significant relationship at 0-10 and exhibited negative significant relationship (r= -0.35, P < 0.05) at10-20 cm soil layer in the reserve forest ecosystem (**Table 60**). However, in the fallow and plantation ecosystems, phosphorus showed a positive significant relationship with total earthworm (r= 0.38, P < 0.05 and r= 0.31, P < 0.05 respectively) at 0-10 cm soil layer (**Table 62 & 64**). Marichal *et al*. (2011) and Bartz *et al*. (2013) also reported a positive correlation between phosphorous and earthworm density.

Effect of potassium

Potassium did not show a significant relationship with the earthworm at 0-10 cm soil layer. However, in the plantation ecosystem, it showed a very high positive significant relationship with *Drawida* sp. (r= 0.48, P < 0.01) and total earthworm density (r = 0.44, P < 0.01) at 10-20 cm soil layer (**Table 58 & 64**) and showed a negative significant relationship with *Eutyphoeus festivus* (r= -0.29, P < 0.05) at 0-10 cm soil layer (**Table 42, 44 & 46**).

Effect of soil organic carbon

Decreasing of earthworm population with increasing depth corresponded with decreasing organic carbon in the soil depths. Soil organic carbon did not show any significant relationship with *Drawida* sp., *Eutyphoeus festivus* and *Perionyx* sp. at 0-10 cm and 10-20 cm soil layers in the reserve forest ecosystem. In the fallow ecosystem also, organic carbon did not show any significant relationship with *Drawida* sp.,*Eutyphoeus* *festivus* and *Perionyx* sp. at 0-10 cm soil layer but at 10-20 cm soil layer, it showed a negative significant relationship with *Drawida* sp. (r= -0.34, P < 0.05) (**Table 56**).Similarly, in the plantation ecosystem also, organic carbon did not show any positive relationship with *Drawida* sp., *Eutyphoeus festivus* and *Perionyx* sp. at 0-10 cm soil layer but at 10-20 cm soil layer, it exhibited a very high positive significant relationship with *Drawida* sp.(r= 0.45, P < 0.01) (**Table 58**). Soil organic carbon exhibited an insignificant relationship with total earthworm density in all the three study sites at 0-10 cm soil layer. However, it showed a positive significant relationship with total earthworm density (r= 0.39, P < 0.05) at 10-20 cm soil layer in the plantation ecosystem (Table 63). Inconsistency and the contrasting relationship between soil organic matter and earthworm population density as observed in the present study have also been reported by Khalaf El-Duweini and Ghabbour (1965), McCartney *et al*. (1997), Gilot (1997), Burtelow *et al*. (1998) and Desjardins *et al*. (2003).

From the above observation and discussion, it may be concluded synergic and cumulative effect of various physico- chemical factors including the climatic regime of the area rather than the single or individual parameter is responsible for the change in population size from time to time.

Table 41: **Correlation and regression between Density of *Perionyx* sp. and soil physical factors (Forest).**

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.06	35	17.974 + 0.003 X	0.04	> 0.05	0
	10-20	NR	35	NR	NR	NR	NR
Soil moisture	0-10	0.42	35	36.751 + 0.518 X	2.66	< 0.05	17.2
	10-20	NR	35	NR	NR	NR	NR
Bulk density	0-10	-0.15	35	1.131 – 0.001 X	-0.89	> 0.05	2.3
	10-20	NR	35	NR	NR	NR	NR
Soil pH.	0-10	0.21	35	5.337 + 0.012 X	1.23	> 0.05	4.2
	10-20	NR	35	NR	NR	NR	NR

Table 42: **Correlation and regression between Density of *Perionyx* sp. and soil nutrients (Forest).**

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.29	35	309.131 – 2.662 X	2.24	< 0.05	16.1
	10-20	NR	35	NR	NR	NR	NR
Phosphorus (P)	0-10	0.28	35	18.372 + 0.270 X	2.31	< 0.05	17.1
	10-20	NR	35	NR	NR	NR	NR
Potassium (K)	0-10	-0.19	35	139.743 – 2.184 X	-1.14	> 0.05	3.7
	10-20	NR	35	NR	NR	NR	NR
Carbon (C)	0-10	-0.09	35	2.445 – 0.008 X	-0.51	> 0.05	0.8
	10-20	NR	35	NR	NR	NR	NR

Table 43: **Correlation and regression between Density of *Perionyx* sp. and soil physical factors (Fallow).**

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.44	35	18.847 + 0.364 X	2.86	< 0.05	19.4
	10-20	0.12	35	19.640 + 0.454 X	0.69	> 0.05	1.4
Soil moisture	0-10	0.28	35	30.429 + 0.803 X	2.18	< 0.05	11.6
	10-20	-0.06	35	26.752 – 0.611 X	-0.36	> 0.05	0.4
Bulk density	0-10	-0.30	35	1.136 – 0.006 X	-2.21	< 0.05	13.1
	10-20	-0.01	35	1.157 – 0.002 X	-0.07	> 0.05	0
Soil pH.	0-10	-0.08	35	5.179 – 0.002 X	-0.10	> 0.05	0
	10-20	0.19	35	5.456 + 0.108 X	1.11	> 0.05	3.5

Table 44: **Correlation and regression between Density of *Perionyx* sp. and soil nutrients (Fallow).**

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.30	35	239.867 – 1.362 X	2.17	< 0.05	11.8
	10-20	-0.17	35	217.218 – 51.220 X	-1.03	> 0.05	3
Phosphorus (P)	0-10	0.28	35	16.774 + 0.632 X	2.66	< 0.05	17.5
	10-20	-0.15	35	15.474 – 6.925 X	-0.88	> 0.05	2.2
Potassium (K)	0-10	-0.08	35	154.729 – 1.385 X	-0.46	> 0.05	0.6
	10-20	0.04	35	94.586 + 7.448 X	0.22	> 0.05	0.1
Carbon (C)	0-10	-0.08	35	2.163 – 0.012 X	-0.44	> 0.05	0.6
	10-20	-0.01	35	1.705 – 0.016 X	-0.03	> 0.05	0

Table 45: Correlation and regression between Density of *Perionyx* sp. and soil physical factors (Plantation).

Variable	**Soil layers**	**r**	**df**	**Y**	**t**	**p**	**Variability (%)**
Soil temp.	0-10	-0.09	35	20.410 – 0.132 X	-0.53	> 0.05	0.8
	10-20	-0.25	35	20.277 – 1.551 X	-1.51	> 0.05	6.3
Soil moisture	0-10	0.11	35	37.771 + 0.493 X	0.66	> 0.05	1.3
	10-20	0.15	35	30.389 + 2.148 X	0.91	> 0.05	2.4
Bulk density	0-10	-0.03	35	1.128 – 0.000 X	-0.17	> 0.05	0.1
	10-20	-0.01	35	1.212 – 0.000 X	-0.03	> 0.05	0
Soil pH.	0-10	0.04	35	5.548 + 0.007 X	0.23	> 0.05	0.2
	10-20	0.22	35	5.297 + 0.137 X	1.29	> 0.05	4.7

Table 46: Correlation and regression between Density of *Perionyx* sp. and soil nutrients (Plantation).

Variable	**Soil layers**	**r**	**df**	**Y**	**t**	**p**	**Variability (%)**
Nitrogen (N)	0-10	0.19	35	256.753 + 25.247 X	1.13	> 0.05	3.6
	10-20	0.12	35	213.780 + 54.812 X	0.72	> 0.05	1.5
Phosphorus (P)	0-10	-0.15	35	18.672 – 2.395 X	-0.89	> 0.05	2.3
	10-20	-0.15	35	14.039 – 5.854 X	-0.86	> 0.05	2.1
Potassium (K)	0-10	0.01	35	115.236 + 50.504 X	0.06	> 0.05	0
	10-20	0.11	35	74.553 + 50.504 X	0.62	> 0.05	1.1
Carbon (C)	0-10	0.04	35	2.244 + 0.041 X	0.25	> 0.05	0.2
	10-20	0.19	35	1.747 + 0.801 X	1.09	> 0.05	3.4

Table 47: Correlation and regression between Density of *Eutyphoeus festivus* and soil physical factors (Forest).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.39	35	14.456 + 0.269 X	2.54	< 0.05	16.1
	10-20	0.18	35	17.677 + 0.270 X	1.06	> 0.05	3.2
Soil moisture	0-10	0.24	35	40.054 + 0.250 X	2.14	< 0.05	12.2
	10-20	0.18	35	29.689 + 0.311 X	1.08	> 0.05	3.3
Bulk density	0-10	-0.33	35	1.166 – 0.004 X	-2.05	< 0.05	11
	10-20	-0.03	35	1.201 – 0.001 X	-0.19	> 0.05	0.1
Soil pH.	0-10	0.15	35	5.325 + 0.012 X	0.89	> 0.05	2.3
	10-20	0.18	35	5.268 + 0.31 X	1.17	> 0.05	3.9

Table 48: **Correlation and regression between Density of *Eutyphoeus festivus* and soil nutrients (Forest).**

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	-0.07	35	296.242 – 0.348 X	-0.43	> 0.05	0.5
	10-20	-0.27	35	259.531 – 2.471 X	-1.74	> 0.05	8.2
Phosphorus (P)	0-10	-0.07	35	20.437 – 0.031 X	-0.39	> 0.05	0.4
	10-20	-0.27	35	16.376 – 0.216 X	-1.62	> 0.05	7.1
Potassium (K)	0-10	-0.13	35	133.166 – 0.632 X	-0.75	> 0.05	1.6
	10-20	-0.09	35	82.839 – 0.834 X	-0.55	> 0.05	0.9
Carbon (C)	0-10	-0.01	35	2.395 – 0.001 X	-0.02	> 0.05	0
	10-20	NR	35	NR	NR	NR	NR

Table 49: Correlation and regression between Density of *Eutyphoeus festivus* and soil physical factors (Fallow).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.38	35	18.501 + 0.147 X	2.43	< 0.05	14.8
	10-20	0.08	35	19.653 + 0.259 X	0.48	> 0.05	0.7
Soil moisture	0-10	0.29	35	28.723 + 0.421 X	2.24	< 0.05	11.3
	10-20	-0.04	35	26.734 – 0.349 X	-0.25	> 0.05	0.2
Bulk density	0-10	-0.10	35	1.127 – 0.000 X	-0.59	> 0.05	1
	10-20	-0.10	35	1.161 – 0.014 X	-0.59	> 0.05	1
Soil pH.	0-10	0.02	35	5.707 + 0.001 X	0.09	> 0.05	0
	10-20	0.01	35	5.478 + 0.007 X	0.08	> 0.05	0

Table 50: Correlation and regression between Density of *Eutyphoeus festivus* and soil nutrients (Fallow).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.39	35	247.470 – 1.500 X	2.46	< 0.05	15.1
	10-20	-0.06	35	215.764 – 0.744 X	-0.34	> 0.05	0.3
Phosphorus (P)	0-10	0.27	35	16.568 + 0.187 X	2.37	< 0.05	14.1
	10-20	-0.08	35	15.315 – 0.158 X	0.45	> 0.05	0.6
Potassium (K)	0-10	-0.06	35	154.913 – 0.369 X	-0.35	> 0.05	0.4
	10-20	0.09	35	94.362 + 0.783 X	0.52	> 0.05	0.8
Carbon (C)	0-10	0.01	35	2.142 + 0.000 X	0.04	> 0.05	0
	10-20	-0.10	35	1.714 – 0.015 X	0.59	> 0.05	1

Table 51: **Correlation and regression between Density of *Eutyphoeus festivus* and soil physical factors (Plantation).**

Variable	**Soil layers**	**r**	**df**	**Y**	**t**	**p**	**Variability (%)**
Soil temp.	0-10	0.35	35	18.452 + 0.098 X	2.19	< 0.05	12.3
	10-20	-0.01	35	20.131 – 0.011 X	-0.15	> 0.05	0
Soil moisture	0-10	0.31	35	34.290 + 0.231 X	2.07	< 0.05	11.5
	10-20	-0.18	35	31.197 – 0.579 X	-1.03	> 0.05	3.0
Bulk density	0-10	-0.29	35	1.155 – 0.002 X	-2.11	< 0.05	10.8
	10-20	0.15	35	1.208 + 0.004 X	0.87	> 0.05	2.2
Soil pH.	0-10	0.16	35	5.459 + 0.005 X	0.96	> 0.05	2.6
	10-20	-0.01	35	5.313 – 0.002 X	-0.07	> 0.05	0

Table 52: Correlation and regression between Density of *Eutyphoeus festivus* and soil nutrients (Plantation).

Variable	**Soil layers**	**r**	**df**	**Y**	**t**	**p**	**Variability (%)**
Nitrogen (N)	0-10	0.27	35	285.650 – 2.615 X	2.31	< 0.05	17.2
	10-20	0.05	35	213.856 + 1.048 X	0.32	> 0.05	0.3
Phosphorus (P)	0-10	0.28	35	15.974 + 0.243 X	2.40	< 0.05	18.1
	10-20	-0.20	35	14.249 – 0.346 X	-1.18	> 0.05	3.9
Potassium (K)	0-10	-0.29	35	128.223 – 1.541 X	-2.15	< 0.05	12.3
	10-20	0.30	35	69.768 + 0.009 X	1.82	> 0.05	8.9
Carbon (C)	0-10	0.13	35	2.178 + 0.009 X	0.78	> 0.05	1.8
	10-20	0.29	35	1.712 + 0.054 X	1.76	> 0.05	8.4

Table 53: **Correlation and regression between Density of *Drawida* sp. and soil physical factors (Forest).**

Variable	**Soil layers**	**r**	**df**	**Y**	**t**	**p**	**Variability (%)**
Soil temp.	0-10	0.43	35	15.948 + 0.183 X	2.76	< 0.01	18.3
	10-20	0.13	35	17.761 +0.165 X	0.76	> 0.05	1.7
Soil moisture	0-10	0.05	35	42.669 + 0.610 X	0.32	> 0.05	0.3
	10-20	-0.08	35	30.180 – 0.108 X	-0.44	> 0.05	0.6
Bulk density	0-10	-0.37	35	1.146 – 0.003 X	-2.29	< 0.05	13.4
	10-20	-0.01	35	1.200 + 0.000 X	-0.61	> 0.05	0
Soil pH.	0-10	0.07	35	5.446 + 0.004 X	0.42	> 0.05	0.5
	10-20	0.15	35	5.276 + 0.020 X	0.90	> 0.05	2.3

Table 54: **Correlation and regression between Density of *Drawida* sp. and soil nutrients (Forest).**

Variable	**Soil layers**	**r**	**df**	**Y**	**t**	**p**	**Variability (%)**
Nitrogen (N)	0-10	0.41	35	310.160 – 1.610 X	2.59	< 0.05	16.5
	10-20	-0.30	35	260.048 – 2.742 X	-1.84	> 0.05	9.1
Phosphorus (P)	0-10	0.29	35	19.102 + 0.088 X	2.23	< 0.05	10.4
	10-20	-0.26	35	16.388 – 0.221 X	-1.57	> 0.05	6.8
Potassium (K)	0-10	0.09	35	121.845 + 0.362 X	0.51	> 0.05	0.8
	10-20	-0.07	35	82.445 – 0.619 X	-0.39	> 0.05	0.4
Carbon (C)	0-10	0.11	35	2.351 + 0.004 X	0.65	> 0.05	1.2
	10-20	0.06	35	1.651 + 0.006 X	0.37	> 0.05	0.4

Table 55: Correlation and regression between Density of *Drawida* sp. and soil physical factors (Fallow).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.79	35	16.798 + 0.245 X	7.42	< 0.01	61.8
	10-20	0.18	35	19.533 + 0.489 X	1.04	> 0.05	3.1
Soil moisture	0-10	0.76	35	21.262 + 0.906 X	6.78	< 0.01	57.5
	10-20	0.15	35	26.175 + 1.113 X	0.91	> 0.05	2.4
Bulk density	0-10	-0.65	35	1.183 -0.005 X	-4.99	< 0.01	42.3
	10-20	-0.13	35	1.163 – 0.016 X	-0.78	> 0.05	1.7
Soil pH.	0-10	0.15	35	5.636 + 0.006 X	0.89	> 0.05	2.3
	10-20	0.06	35	5.475 + 0.007 X	0.09	> 0.05	0

Table 56: Correlation and regression between Density of *Drawida* sp. and soil nutrients (Fallow).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.31	35	246.280 – 0.985 X	2.25	< 0.05	10.7
	10-20	0.07	35	214.191 + 10.058 X	0.42	> 0.05	0.5
Phosphorus (P)	0-10	0.34	35	15.773 + 0.231 X	2.13	< 0.05	11.8
	10-20	0.24	35	14.628 + 5.380 X	1.47	> 0.05	6
Potassium (K)	0-10	-0.07	35	155.633 – 0.359 X	-0.41	> 0.05	0.5
	10-20	-0.19	35	96.786 – 17.664 X	-1.11	> 0.05	3.5
Carbon (C)	0-10	0.17	35	2.077 + 0.008 X	0.99	> 0.05	2.8
	10-20	-0.34	35	1.761 – 0.520 X	-2.07	< 0.05	11.2

Table 57: Correlation and regression between Density of *Drawida* sp. and soil physical factors (Plantation).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.42	35	18.908 + 0.140 X	2.67	< 0.05	17.37
	10-20	0.09	35	20.008 + 0.156 X	0.51	> 0.05	0.8
Soil moisture	0-10	0.31	35	35.770 + 0.289 X	2.31	< 0.05	11.2
	10-20	-0.14	35	31.016 – 0.574 X	-0.84	> 0.05	2.0
Bulk density	0-10	-0.12	35	1.134 – 0.000 X	-0.70	> 0.05	1.4
	10-20	-0.03	35	1.213 – 0.001 X	-0.19	> 0.05	0.1
Soil pH.	0-10	0.03	35	5.548 + 0.001 X	0.15	> 0.05	0.1
	10-20	0.31	35	5.271 + 0.057 X	1.89	> 0.05	9.6

Table 58: Correlation and regression between Density of *Drawida* sp. and soil nutrients (Plantation).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.40	35	281.432 – 3.546 X	2.52	< 0.05	15.8
	10-20	-0.07	35	215.842 – 2.006 X	-0.40	> 0.05	0.5
Phosphorus (P)	0-10	0.29	35	16.864 + 0.227 X	2.27	< 0.05	12.1
	10-20	-0.04	35	13.981 – 0.107 X	-0.24	> 0.05	0.2
Potassium (K)	0-10	-0.19	35	122.413 – 1.407 X	-1.15	> 0.05	3.7
	10-20	0.48	35	67.923 + 15.061 X	3.22	< 0.01	23.3
Carbon (C)	0-10	-0.01	35	2.258 + 0.000 X	-0.04	> 0.05	0
	10-20	0.45	35	1.698 + 0.128 X	2.96	< 0.01	20.5

Table 59: Correlation and regression between Density of total earthworm and soil physical factors (Forest).

Variable	**Soil layers**	**r**	**df**	**Y**	**t**	**p**	**Variability (%)**
Soil temp.	0-10	0.49	35	13.795 + 0.626 X	3.27	< 0.01	24.1
	10-20	0.19	35	17.726 + 0.529 X	0.82	> 0.05	1.9
Soil moisture	0-10	0.39	35	34.572 + 1.305 X	2.44	< 0.05	14.9
	10-20	0.05	35	29.936 + 0.212 X	0.29	> 0.05	0.2
Bulk density	0-10	-0.50	35	1.190 – 0.011 X	-3.39	< 0.01	25.2
	10-20	0.03	35	1.201 – 0.004 X	-0.19	> 0.05	0.1
Soil pH.	0-10	0.20	35	5.278 + 0.310 X	1.19	> 0.05	4.0
	10-20	0.17	35	5.270 + 0.069 X	1.02	> 0.05	3.0

Table 60: Correlation and regression between Density of total earthworm and soil nutrients (Forest).

Variable	**Soil layers**	**r**	**df**	**Y**	**t**	**p**	**Variability (%)**
Nitrogen (N)	0-10	0.35	35	320.206 – 4.825 X	2.15	< 0.05	12
	10-20	-0.34	35	261.970 – 8.351 X	-2.13	< 0.05	11.8
Phosphorus (P)	0-10	0.24	35	18.198 + 0.325 X	1.44	> 0.05	5.7
	10-20	-0.35	35	16.640 – 0.790 X	-2.16	< 0.05	12.1
Potassium (K)	0-10	-0.08	35	132.356 – 1.117 X	-0.45	> 0.05	0.6
	10-20	-0.08	35	83.020 – 2.054 X	-0.48	> 0.05	0.7
Carbon (C)	0-10	0.05	35	2.360 + 0.006 X	0.28	> 0.05	0.2
	10-20	-0.06	35	1.675 – 0.015 X	-0.35	> 0.05	0.3

Table 61: Correlation and regression between Density of total earthworm and soil physical factors (Fallow).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.79	35	15.818 + 0.990 X	7.51	< 0.01	62.4
	10-20	0.18	35	19.478 + 1.813 X	1.06	> 0.05	3.2
Soil moisture	0-10	0.68	35	19.478 + 3.287 X	5.48	< 0.01	46.9
	10-20	0.03	35	26.535 + 0.664 X	0.15	> 0.05	0.1
Bulk density	0-10	-0.47	35	1.179 – 0.015 X	-3.10	< 0.01	22.1
	10-20	-0.13	35	1.164 – 0.054 X	-0.73	> 0.05	1.6
Soil pH.	0-10	0.13	35	5.269 – 0.020 X	0.74	> 0.05	1.6
	10-20	0.06	35	5.464 + 0.097 X	0.37	> 0.05	0.4

Table 62: Correlation and regression between Density of total earthworm and soil nutrients (Fallow).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.40	35	252.157 – 4.979 X	2.51	< 0.05	15.6
	10-20	-0.07	35	215.967 – 5.876 X	-0.38	> 0.05	0.4
Phosphorus (P)	0-10	0.38	35	14.817 + 1.023 X	2.42	< 0.05	14.7
	10-20	-0.07	35	15.325 – 0.964 X	0.39	> 0.05	0.4
Potassium (K)	0-10	-0.02	35	153.455 – 0.328 X	-0.11	> 0.05	0
	10-20	0.07	35	94.339 + 4.544 X	0.43	> 0.05	0.5
Carbon (C)	0-10	0.06	35	2.111 + 0.011 X	0.37	> 0.05	0.4
	10-20	-0.13	35	1.720 – 0.133 X	-0.77	> 0.05	1.7

Table 63: **Correlation and regression between Density of total earthworm and soil physical factors (Plantation).**

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.51	35	17.106 + 0.627 X	3.41	< 0.01	25.5
	10-20	-0.03	35	20.161 – 0.146 X	-0.15	> 0.05	0.1
Soil moisture	0-10	0.39	35	31.150 + 1.473 X	2.50	< 0.05	15.5
	10-20	-0.17	35	31.233 – 2.156 X	-0.98	> 0.05	2.7
Bulk density	0-10	-0.30	35	1.165 – 0.008 X	-2.31	< 0.05	14.7
	10-20	0.10	35	1.209 + 0.010 X	0.59	> 0.05	1
Soil pH.	0-10	0.16	35	5.441 + 0.024 X	0.92	> 0.05	2.4
	10-20	0.19	35	5.279 + 0.111 X	1.11	> 0.05	3.5

Table 64: **Correlation and regression between Density of total earthworm and soil nutrients (Plantation).**

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.37	35	294.953 – 12.614 X	2.31	< 0.05	13.6
	10-20	-0.03	35	215.360 – 2.612 X	-0.17	> 0.05	0.1
Phosphorus (P)	0-10	0.31	35	14.849 + 1.278 X	2.15	< 0.05	12.8
	10-20	-0.17	35	14.210 – 1.394 X	-1.02	> 0.05	3.0
Potassium (K)	0-10	-0.35	35	139.157 – 9.662 X	-2.15	< 0.05	11.9
	10-20	0.44	35	66.956 + 42.237 X	2.83	< 0.01	19.1
Carbon (C)	0-10	0.14	35	2.170 + 0.035 X	0.83	> 0.05	2.0
	10-20	0.39	35	1.693 + 0.341 X	2.47	< 0.05	15.2

Effect of physic-chemical factors and soil nutrients on earthworm biomass

The effect of various physico-chemical factors on the biomass of three dominant species of *Perionyx* sp. (epigeic), *Eutyphoeus festivus* (endogeic), *Drawida* sp. (anecic) and total earthworm biomass is shown from **Table 65-88**.

Effect of soil Temperature:

In the reserve forest ecosystem, the soil temperature showed positive significant relationship with the biomass of *Eutyphoeus festivus* (r= 0.27, P < 0.05) and *Drawida* sp., (r= 0.49, P < 0.01) at 0-10 cm soil layer (**Table 71 & 77**). It showed a negative significant relationship with biomass of *Perionyx* sp. (r= -0.29, P < 0.05) in the same soil layer **(Table 65)**. However, there was a positive significant relationship with the total earthworm biomass (r= 0.49.P < 0.01) at 0-10 cm soil layer. Similarly in the plantation site, temperature showed positive significant relationship with the biomass of *Eutyphoeus fe*stivus (r= 0.44, P < 0.01), *Drawida* sp. (r=0.33, P<0.05) and total earthworm biomass (r= 0.59, P < 0.01) (**Table 75, 81 & 88)** and a negative significant relationship with the biomass of *Perionyx* sp. (r= -0.09, P < 0.05) at 0-10 cm layer **(Table 70**). In the fallow site, it showed a positive correlation with the biomass of *Perionyx* sp. (r= 0.31, P < 0.05), *Eutyphoeus festivus* (r= 0.37, P < 0.05), *Drawida* sp. (r= 0.62, P < 0.01) and total earthworm (r= 0.69, P < 0.01) at 0-10 cm soil layer (**Table 67, 73, 79 & 85**). While in the 10-20 cm soil layer soil temperature showed negative relationship with some species and with some it did not show any significant relationship. The test however indicated that soil temperature plays a crucial role in the distribution of earthworm biomass.

Effect of soil Moisture

Soil moisture content was higher in the 0-10 cm soil layer and exhibited a high positive significant relationship with the biomass of *Perionyx* sp. (r= 0.46, $P < 0.01$) ,*Drawida* sp. (r= 0.30, $P < 0.05$) and total earthworms (r= 0.30, $P < 0.05$) in the reserve forest ecosystem (**Table 65, 77, & 83**). However, at 10-20 cm soil layer it showed no significant relationship with any of the earthworm species.

In the fallow ecosystem, moisture content showed a very high positive significant relationship with biomass of *Perionyx* sp. (r= 0.30, $P < 0.05$), *Eutyphoeus festivus* (r= 0.38, $P < 0.05$),*Drawida* sp. (r= 0.56, $P < 0.01$), , and total earthworm density (r= 0.65, $P < 0.01$) respectively (**Table 67, 73, 79 & 85**). At 10-20 cm soil layer, no significant relationships were exhibited.

And in the plantation ecosystem, moisture content exhibited positive significant relationship with the biomass of *Eutyphoeus festivus* (r= 0.28, $P < 0.05$) , *Drawida* sp. (r= 0.29, $P < 0.05$) and total Earthworms (r= 0.37, $P < 0.05$) (**Table 75, 81 & 87**).But it did not show positive relationship with *Perionyx* sp. at 0-10 cm soil layer. While at 10-20 cm soil layer, moisture content did not show any positive significant relationship.

At the 10-20 cm soil layers though, moisture content showed an insignificant or negative relationship with the biomass of the earthworm species. The trend point to the fact that with increasing depth in the soil, moisture content also decreases, resulting in a concentration of earthworms at the top layer. Wood (1974) also demonstrated a strong positive correlation between earthworm biomass and increased soil moisture content for top-soil inhabiting earthworm species in south-eastern Australia.

Effect of bulk density

The value of bulk density exhibited significant negative relationship with the biomass of almost all the earthworm species in the reserve forest ecosystem i.e. with *Drawida* sp. (r= -0.36, P < 0.05) and with the total earthworm (r= -0.38, P < 0.05) at 0-10 cm soil layer (**Table 77 & 83)**. The pattern was almost similar in both the plantation and fallow ecosystems. In the 10-20 cm soil layer also, it showed a similar negative relationship or no significant relationship with almost all the earthworms.

Effect of soil pH

The soil pH showed significant positive relationship with the biomass of *Eutyphoeus festivus* (r= 0.29, P < 0.05), *Drawida* sp. (r= 0.33, P < 0.05) and total earthworm (r= 0.35, P < 0.050) at 0-10 cm soil layer in the reserve forest ecosystem (**Table 71, 77, & 83**). While in fallow ecosystem, it showed positive significant relationship with *Eutyphoeus festivus* (r= 0.27, P < 0.05) and total earthworm (r= 0.29, P < 0.05) at 0-10 cm soil layer (**Table 73 & 85**). In the plantation ecosystem, it did not show any positive relationship with any earthworm but at 10-20 cm soil layer, it showed positive significant relationship with *Perionyx* sp. (r= 0.30, P < 0.05) and *Drawida* sp. (r= 0.32, P < 0.05) (**Table 81 & 69**).

Effect of available nitrogen

Available nitrogen content showed a positive significant relationship with *Perionyx* sp. (r= 0.30, P < 0.05), *Drawida* sp. *(*r= 0.41, P < 0.05) and total earthworm (r= 0.35, P < 0.05) at 0-10 cm soil layers in the reserve forest ecosystem (**Table 66, 78 & 84)**. It also showed positive significant relationship with *Eutyphoeus festivus* (r= 0.39, P < 0.05),*Drawida* sp. (r= 0.31, P < 0.05) and total earthworm (r= 0.40, < P0.05) in the fallow ecosystem (**Table 74, 80 & 86)**. Similarly at 0-10 cm soil layer in the plantation site, nitrogen exhibited positive significant relationship with *Perionyx* sp. (r= 0.29, P < 0.05), *Eutyphoeus festivus* (r= 0.37, P < 0.05), *Drawida* sp. (r= 0.39, P < 0.05) and total earthworm (r= 0.37, P < 0.05) (**Table 70, 76, 82 & 88**). At 10-20 cm soil layers, it showed significant positive relationship with *Eutyphoeus festivus* (r= 0.29, P < 0.05, r= 0.29, P < 0.05) in reserve forest and plantation, with *perionyx* sp (r= 0.28, P < 0.05, r= -0.36, P < 0.05) in fallow and plantation and finally with total earthworm (r= 0.34, P < 0.05, r= 0.34, P < 0.05) in reserve forest and plantation respectively (**Table 72, 74, 68, 70, 84 & 88**).

Effect of phosphorus

The phosphorus showed positive significant relationship with *Perionyx* sp. (r= -0.31, P < 0.05), *Drawida* sp. (r= -0.23, P < 0.05) and total earthworm (r= 0.29, P < 0.05) at 0-10 cm soil layers in the reserve forest ecosystem (**Table 66, 78 & 84**). However it exhibited insignificant relationship with *Eutyphoeus festivus*. In the fallow ecosystem phosphorus showed positive significant relationship with *Perionyx* sp. (r= 0.27, P < 0.05),*Eutyphoeus festivus* (r= 0.28, P < 0.05) ,*Drawida* sp. (r= 0.34, P < 0.05) and total earthworm (r= 0.38, P < 0.05) at 0-10 cm soil layers(**Table 68, 74, 80 & 86**). In the plantation ecosystem also, it showed positive significant relationship with *Eutyphoeus festivus* (r= 0.28, P < 0.05), *Drawida* sp. (r= 0.28, P < 0.05) and total earthworm (r= 0.31, P < 0.05) at the 0-10 cm soil layers (**Table 76, 82 & 88**).

Effect of potassium

At 0-10 cm soil layer, potassium showed significant negative relationship with *Perionyx* sp. (r= -0.27, P < 0.05), *Eutyphoeus festivus* (r= -0.30, P < 0.05) and total earthworm biomass (r= -0.27, P < 0.05) in the reserve forest (**Table 66, 72 & 84**). Interestingly though, at 10-20 cm soil layer in the plantation ecosystem, it showed a high positive significant relationship with *Eutyphoeus festivus* (r= 0.32, P < 0.05), *Drawida* sp.

(r= 0.48, P < 0.01) and total earthworm density (r= 0.34, P < 0.01) (**Table 76, 82, & 88**). Potassium exhibited insignificant relationship with *Perionyx sp.* in the fallow and plantation ecosystem at both 0-10 and 10-20 cm soil layers respectively.

Effect of soil organic carbon

Soil organic carbon did not show any significant relationship with *Perionyx* sp.,*Eutyphoeus festivus*, and *Drawida* sp.biomass at 0-10 cm and 10-20 cm soil layers in the reserve forest ecosystem (**Table 66, 72 & 78**). In the fallow ecosystem also, organic carbon did not show any significant relationship with *Drawida* sp., and *Perionyx* sp. at 0-10 cm soil layer but with *Eutyphoeus festivus* there was a significant positive relationship (r= 0.36, P < 0.05) (**Table 74**).At 10-20 cm soil layer, it showed a negative significant relationship with *Drawida sp*. (r= -0.34, P < 0.05). Similarly, in the plantation ecosystem, organic carbon did not show any positive relationship with *Drawida* sp. but exhibited positive significant relationship with *Perionyx* sp. (r= 0.30, P < 0.05) and *Eutyphoeus festivus* (r= 0.27, P <0.05) at 0-10 cm soil layer (**Table 70 & 76**). However, with *Drawida* sp. it showed a negative significant relationship (r= 0.27, P < 0.05) (**Table 82**) and at 10-20 cm soil layer, it exhibited a high positive significant relationship with *Perionyx* sp. and *Eutyphoeus festivus* (r= 0.17, P < 0.01) (r= 0.47, P < 0.05) (**Table 76 & 70**).

Soil organic carbon exhibited an insignificant relationship with total earthworm biomass in the reserve forest and fallow ecosystems at both 0-10 and 10-20 cm soil layer. However, it showed a positive significant relationship with total earthworm biomass (r= 0.28, P < 0.05) at 0-10 cm soil layer in the plantation ecosystem (**Table 88**).

Table 65: Correlation and regression between Biomass of *Perionyx* sp. and soil physical factors (Forest).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	-0.29	35	19.254 – 0.196 X	-2.27	< 0.05	15.2
	10-20	NR	35	NR	NR	NR	NR
Soil moisture	0-10	0.46	35	36.344 + 1.105 X	2.98	< 0.01	20.7
	10-20	NR	35	NR	NR	NR	NR
Bulk density	0-10	-0.05	35	1.120 – 0.000 X	-0.27	> 0.05	0
	10-20	NR	35	NR	NR	NR	NR
Soil pH.	0-10	0.02	35	5.474 + 0.002 X	0.12	> 0.05	0
	10-20	NR	35	NR	NR	NR	NR

Table 66: Correlation and regression between Biomass of *Perionyx* sp. and soil nutrients (Forest).

Variable	Soil layers	r	df	Y	t	P	Variability (%)
Nitrogen (N)	0-10	0.30	35	309.131 – 2.662 X	2.31	< 0.05	14.7
	10-20	NR	35	NR	NR	NR	NR
Phosphorus (P)	0-10	0.31	35	18.372 + 2.700 X	2.42	< 0.05	15.2
	10-20	NR	35	NR	NR	NR	NR
Potassium (K)	0-10	-0.27	35	139.743 – 2.184 X	-2.14	< 0.05	11.6
	10-20	NR	35	NR	NR	NR	NR
Carbon (C)	0-10	-0.09	35	2.445 – 0.008 X	-0.51	> 0.05	0.8
	10-20	NR	35	NR	NR	NR	NR

Table 67: Correlation and regression between Biomass of *Perionyx* sp. and soil physical factors (Fallow).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.31	35	19.412 + 0.316 X	2.21	< 0.05	15.1
	10-20	0.12	35	19.460 + 2.44 X	0.69	> 0.05	0.8
Soil moisture	0-10	0.30	35	31.745 + 0.655 X	2.13	< 0.05	12
	10-20	-0.06	35	26.750 – 3.239 X	-0.36	> 0.05	0
Bulk density	0-10	-0.27	35	1.125 – 0.004 X	-2.11	< 0.05	11.4
	10-20	-0.01	35	1.157 – 0.011 X	-0.07	> 0.05	0.4
Soil pH.	0-10	-0.08	35	5.731 – 0.011 X	-0.47	> 0.05	0.5
	10-20	0.19	35	5.455 + 0.592 X	1.14	> 0.05	1

Table 68: Correlation and regression between Biomass of *Perionyx* sp. and soil nutrients (Fallow)

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	-0.13	35	239.867 – 1.362 X	-0.73	> 0.05	1.6
	10-20	0.28	35	217.218 – 51.220 X	2.05	< 0.05	11.1
Phosphorus (P)	0-10	0.27	35	16.774 + 0.632 X	2.14	< 0.05	11.7
	10-20	-0.15	35	15.474 – 6.925 X	-0.88	> 0.05	2.2
Potassium (K)	0-10	-0.08	35	154.729 – 1.385 X	-0.46	> 0.05	0.6
	10-20	0.04	35	94.586 + 7.448 X	0.22	> 0.05	0.1
Carbon (C)	0-10	-0.08	35	2.163 – 0.012 X	-0.44	> 0.05	0.6
	10-20	-0.01	35	1.705 -0.016 X	-0.03	> 0.05	0

Table 69: Correlation and regression between Biomass of *Perionyx* sp. and soil physical factors (Plantation).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	-0.09	35	20.418 – 0.669 X	-0.53	> 0.05	0.1
	10-20	-0.28	35	20.277 – 8.227 X	-2.12	< 0.05	10.6
Soil moisture	0-10	0.03	35	38.309 + 0.565 X	0.15	> 0.05	0.1
	10-20	0.15	35	30.389 + 11.392 X	0.91	> 0.05	2.4
Bulk density	0-10	-0.1	35	1.131 – 0.015 X	-0.58	> 0.05	1
	10-20	-0.01	35	1.212 – 0.003 X	-0.03	> 0.05	0
Soil pH.	0-10	-0.02	35	5.564 – 0.021 X	-0.14	> 0.05	0
	10-20	0.30	35	5.297 + 0.729 X	2.20	< 0.05	14.5

Table 70: Correlation and regression between Biomass of *Perionyx* sp. and soil nutrients (Plantation).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.29	35	256.753 + 25.247 X	2.13	< 0.05	10.6
	10-20	0.36	35	205.196 – 74.396 X	2.34	< 0.05	12.9
Phosphorus (P)	0-10	-0.15	35	18.672 – 2.395 X	-0.89	> 0.05	2.3
	10-20	0.07	35	14.395 + 0.943 X	0.41	> 0.05	0.5
Potassium (K)	0-10	-0.08	35	110.804 – 7.855 X	-0.47	> 0.05	0.6
	10-20	-0.12	35	72.533 – 18.309 X	-0.71	> 0.05	1.3
Carbon (C)	0-10	0.30	35	3.196 + 1.261 X	2.12	< 0.05	11
	10-20	0.47	35	2.680 + 6.593 X	3.22	< 0.05	21.8

Table 71: Correlation and regression between Biomass of *Eutyphoeus festivus* and soil physical factors (Forest).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.27	35	16.780 + 0.107 X	2.32	< 0.05	14.1
	10-20	0.16	35	17.756 + 0.121 X	0.93	> 0.05	2.5
Soil moisture	0-10	-0.09	35	44.324 – 0.084 X	-0.46	> 0.05	0.4
	10-20	-0.02	35	30.064 – 0.015 X	-0.09	> 0.05	0
Bulk density	0-10	-0.03	35	1.118 – 0.000 X	-0.16	> 0.05	0
	10-20	-0.04	35	1.201 – 0.000 X	-0.23	> 0.05	0.2
Soil pH.	0-10	0.29	35	5.343 + 0.013 X	2.47	< 0.05	16.2
	10-20	0.13	35	5.283 + 0.0011 X	0.78	> 0.05	0.2

Table 72: Correlation and regression between Biomass of *Eutyphoeus festivus* and soil nutrients (Forest)

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	-0.07	35	296.242 – 0.348 X	-0.43	> 0.05	0.5
	10-20	0.29	35	259.531 – 2.471 X	2.14	< 0.05	18.2
Phosphorus (P)	0-10	-0.07	35	20.437 – 0.310 X	-0.39	> 0.05	0.4
	10-20	-0.27	35	16.376 – 0.216 X	-2.32	< 0.05	20.1
Potassium (K)	0-10	-0.30	35	133.166 – 0.632 X	-2.75	< 0.05	31.6
	10-20	-0.09	35	82.839 – 0.834 X	-0.55	> 0.05	0.9
Carbon (C)	0-10	-0.4	35	8.395 – 0.000 X	-0.02	> 0.05	0
	10-20	NR	35	NR	NR	NR	NR

Table 73: Correlation and regression between Biomass of *Eutyphoeus festivus* and soil physical factors (Fallow).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.37	35	19.062 + 0.131 X	2.28	< 0.05	37.1
	10-20	0.06	35	19.697 + 0.055 X	0.35	> 0.05	0
Soil moisture	0-10	0.38	35	29.387 + 0.522 X	2.38	< 0.05	14
	10-20	0.05	35	29.556 + 0.112 X	0.28	> 0.05	0
Bulk density	0-10	-0.33	35	1.126 – 0.001 X	-2.77	< 0.05	15.8
	10-20	-0.11	35	1.159 – 0.004 X	-0.63	> 0.05	1
Soil pH.	0-10	0.27	35	5.677 + 0.006 X	2.45	< 0.05	14.2
	10-20	0.24	35	5.456 + 0.033 X	2.12	< 0.05	11.4

Table 74: Correlation and regression between Biomass of *Eutyphoeus festivus* and soil nutrients (Fallow).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.39	35	247.470 – 1.50 X	2.46	< 0.05	15.1
	10-20	-0.06	35	215.764 – 0.744 X	-0.34	> 0.05	0.3
Phosphorus (P)	0-10	0.28	35	16.568 + 0.187 X	2.37	< 0.05	14.7
	10-20	-0.08	35	15.315 – 0.158 X	-0.45	> 0.05	0.6
Potassium (K)	0-10	-0.06	35	154.913 – 0.369 X	-0.35	> 0.05	0.4
	10-20	0.09	35	154.913 + 0.783 X	0.52	> 0.05	0.8
Carbon (C)	0-10	0.36	35	2.142 + 0.001 X	2.13	< 0.05	12.1
	10-20	-0.1	35	1.714 – 0.015 X	-0.59	> 0.05	1

Table 75: Correlation and regression between Biomass of *Eutyphoeus festivus* and soil physical factors (Plantation).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.44	35	18.226 + 0.243 X	2.89	< 0.01	19.7
	10-20	-0.08	35	20.225 – 0.114 X	-0.47	> 0.05	0.6
Soil moisture	0-10	0.28	35	35.520 + 0.359 X	2.30	< 0.05	14.1
	10-20	-0.12	35	30.977 – 0.003 X	-0.73	> 0.05	1.5
Bulk density	0-10	-0.28	35	1.152 – 0.397 X	-2.23	< 0.05	17.6
	10-20	0.16	35	1.208 + 0.004 X	0.93	> 0.05	2.5
Soil pH.	0-10	-0.05	35	5.586 – 0.003 X	-0.29	> 0.05	0
	10-20	0.04	35	5.306 + 0.006 X	0.23	> 0.05	0

Table 76: Correlation and regression between Biomass of *Eutyphoeus festivus* and soil nutrients (Plantation)

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.37	35	285.650 – 2.615 X	2.62	< 0.05	27.2
	10-20	-0.29	35	209.025 – 6.905 X	-2.21	< 0.05	18.6
Phosphorus (P)	0-10	0.28	35	15.974 + 0.243 X	2.24	< 0.05	14.3
	10-20	0.04	35	14.374 + 1.167 X	0.26	> 0.05	0.2
Potassium (K)	0-10	-0.13	35	117.666 – 1.167 X	-0.82	> 0.05	1.8
	10-20	0.32	35	66.008 + 5.035 X	2.25	< 0.05	15.7
Carbon (C)	0-10	0.27	35	4.725 – 0.144 X	-2.31	< 0.05	14.5
	10-20	0.17	35	2.811 + 0.325 X	2.17	< 0.05	11.2

Table 77: Correlation and regression between Biomass of *Drawida* sp. and soil physical factors (Forest).

Variable	**Soil layers**	**r**	**df**	**Y**	**t**	**p**	**Variability (%)**
Soil temp.	0-10	0.49	35	16.182 + 0.164 X	3.24	< 0.01	24.6
	10-20	0.22	35	17.648 + 0.178 X	1.32	> 0.05	4.9
Soil moisture	0-10	0.30	35	41.921 + 0.129 X	2.21	< 0.05	12.1
	10-20	0.01	35	30.022 + 0.008 X	0.05	> 0.05	0
Bulk density	0-10	-0.36	35	1.139 – 0.002 X	-2.28	< 0.05	13.2
	10-20	-0.02	35	1.200 – 0.000 X	-0.12	> 0.05	0
Soil pH.	0-10	0.33	35	5.335 + 0.014 X	2.07	< 0.05	11.2
	10-20	0.14	35	5.281 + 0.120 X	0.83	> 0.05	0.2

Table 78: Correlation and regression between Biomass of *Drawida* sp. and soil nutrients (Forest).

Variable	**Soil layers**	**r**	**df**	**Y**	**t**	**p**	**Variability (%)**
Nitrogen (N)	0-10	0.41	35	310.160 – 1.610 X	2.59	< 0.05	16.5
	10-20	-0.30	35	260.048 – 2.742 X	-2.10	< 0.05	10.1
Phosphorus (P)	0-10	0.23	35	19.102 + 0.088 X	2.36	< 0.05	15.1
	10-20	-0.26	35	16.388 – 0.221 X	-2.57	< 0.05	16.1
Potassium (K)	0-10	0.09	35	121.845 + 0.362 X	0.51	> 0.05	0.8
	10-20	-0.07	35	82.445 – 0.619 X	-0.39	> 0.05	0.4
Carbon (C)	0-10	0.11	35	2.351 + 0.004 X	0.65	> 0.05	1.2
	10-20	0.06	35	1.651 +0.006 X	0.37	> 0.05	0.4

Table 79: Correlation and regression between Biomass of *Drawida* sp. and soil physical factors (Fallow).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.62	35	18.320 + 0.164 X	4.55	< 0.01	38.2
	10-20	0.09	35	17.648 + 0.178 X	0.52	> 0.05	0.2
Soil moisture	0-10	0.56	35	41.921 + 0.129 X	3.97	< 0.01	32.4
	10-20	0.09	35	30.022 + 0.008 X	0.50	> 0.05	0.2
Bulk density	0-10	-0.53	35	1.139 – 0.002 X	-3.65	< 0.05	28.1
	10-20	-0.11	35	1.200 – 0.000 X	-0.63	> 0.05	1.4
Soil pH.	0-10	0.11	35	5.335 + 0.014 X	0.67	> 0.05	1
	10-20	-0.01	35	5.281 + 0.120 X	-0.01	> 0.05	0

Table 80: Correlation and regression between Biomass of *Drawida* sp. and soil nutrients (Fallow).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.31	35	246.280 – 0.985 X	2.89	< 0.05	19.6
	10-20	0.07	35	214.191 + 10.058 X	0.42	> 0.05	0.5
Phosphorus (P)	0-10	0.34	35	15.773 + 0.231 X	2.13	< 0.05	11.8
	10-20	0.28	35	14.628 + 5.380 X	2.22	< 0.05	12.1
Potassium (K)	0-10	-0.07	35	155.633 + 0.359 X	-0.41	> 0.05	0.5
	10-20	-0.19	35	96.786 – 17.664 X	-1.11	> 0.05	3.5
Carbon (C)	0-10	0.27	35	2.077 + 0.008 X	0.99	> 0.05	2.8
	10-20	-0.34	35	1.761 – 0.520 X	-2.07	< 0.05	11.2

Table 81: Correlation and regression between Biomass of *Drawida* sp. and soil physical factors (Plantation).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.33	35	19.415 + 0.165 X	2.05	< 0.05	11
	10-20	0.05	35	20.070 + 0.097 X	0.26	> 0.05	0.2
Soil moisture	0-10	0.29	35	36.799 + 0.343 X	2.36	< 0.05	13.1
	10-20	-0.21	35	31.119 – 1.013 X	-1.25	> 0.05	4.4
Bulk density	0-10	-0.28	35	1.136 – 0.002 X	-2.14	< 0.05	12.2
	10-20	0.04	35	1.211 + 0.001 X	0.20	> 0.05	0
Soil pH.	0-10	0.08	35	5.533 + 0.005 X	0.49	> 0.05	0.1
	10-20	0.32	35	5.276 + 0.070 X	2.11	< 0.05	11.1

Table 82: Correlation and regression between Biomass of *Drawida* sp. and soil nutrients (Plantation).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.39	35	281.432 – 3.546 X	2.52	< 0.05	15.8
	10-20	-0.05	35	201.032 – 2.206 X	-0.32	> 0.05	0.3
Phosphorus (P)	0-10	0.28	35	16.864 + 0.227 X	2.27	< 0.05	13
	10-20	-0.03	35	14.506 – 0.087 X	-0.19	> 0.05	0.1
Potassium (K)	0-10	-0.11	35	112.104 – 0.844 X	-0.65	> 0.05	1.1
	10-20	0.48	35	63.830 + 15.497 X	3.32	< 0.01	22.9
Carbon (C)	0-10	-0.27	35	4.060 – 0.104 X	-2.21	< 0.05	11.1
	10-20	-0.01	35	3.164 – 0.032 X	-0.07	> 0.05	0

Table 83: Correlation and regression between Biomass of total earthworm and soil physical factors (Forest).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.49	35	14.643 + 0.581 X	3.27	< 0.01	23.9
	10-20	0.18	35	17.647 + 0.395 X	1.09	> 0.05	3.4
Soil moisture	0-10	0.30	35	38.596 + 0.822 X	2.18	< 0.05	14.3
	10-20	0.03	35	29.975 + 0.740 X	0.18	> 0.05	0.01
Bulk density	0-10	-0.38	35	1.161 – 0.008 X	-2.42	< 0.05	14.7
	10-20	-0.05	35	1.202 – 0.003 X	-0.29	> 0.05	0.3
Soil pH.	0-10	0.35	35	5.194 + 0.051 X	2.18	< 0.05	12.3
	10-20	0.16	35	5.273 + 0.035 X	0.03	> 0.05	0.3

Table 84: Correlation and regression between Biomass of total earthworm and soil nutrients (Forest).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.35	35	320.206 – 4.825 X	2.15	< 0.05	12
	10-20	0.34	35	261.970 – 8.351 X	2.13	< 0.05	11.8
Phosphorus (P)	0-10	0.29	35	18.198 + 0.325 X	2.11	< 0.05	11.2
	10-20	-0.35	35	16.640 – 0.790 X	-2.16	< 0.05	12.1
Potassium (K)	0-10	-0.08	35	83.020 – 2.054 X	-0.45	> 0.05	0.6
	10-20	-0.08	35	80.011 – 2.011 X	-0.48	> 0.05	0.7
Carbon (C)	0-10	0.09	35	2.360 + 0.006 X	0.28	> 0.05	0.2
	10-20	-0.06	35	1.675 – 0.015 X	-0.35	> 0.05	0.3

Table 85: Correlation and regression between Biomass of total earthworm and soil physical factors (Fallow).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.69	35	17.567 + 0.809 X	5.53	< 0.01	47.7
	10-20	0.08	35	19.675 + 0.491 X	0.45	> 0.05	0.5
Soil moisture	0-10	0.65	35	24.251 + 2.939 X	5.02	< 0.01	43.1
	10-20	0.05	35	26.532 + 0.820 X	0.29	> 0.05	0
Bulk density	0-10	-0.48	35	1.159 – 0.041 X	-3.17	< 0.05	23
	10-20	-0.12	35	1.160 – 0.032 X	-0.69	> 0.05	0.1
Soil pH.	0-10	0.29	35	5.623 + 0.310 X	2.12	< 0.05	12.01
	10-20	0.26	35	5.449 + 0.246 X	1.55	> 0.05	1

Table 86: Correlation and regression between Biomass of total earthworm and soil nutrients (Fallow)

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.40	35	252.157 – 4.979 X	2.51	< 0.05	15.6
	10-20	-0.07	35	215.967 – 5.876 X	-0.38	> 0.05	0.4
Phosphorus (P)	0-10	0.38	35	14.817 + 1.023 X	2.42	< 0.05	14.7
	10-20	-0.07	35	15.325 – 0.964 X	-0.39	> 0.05	0.4
Potassium (K)	0-10	-0.02	35	153.455 – 0.328 X	-0.09	> 0.05	0
	10-20	0.07	35	94.339 + 4.544 X	0.43	> 0.05	0.5
Carbon (C)	0-10	-0.06	35	2.111 + 0.011 X	-0.36	> 0.05	0.4
	10-20	-0.13	35	1.720 – 0.133 X	-0.77	> 0.05	1.7

Table 87: Correlation and regression between Biomass of total earthworm and soil physical factors (Plantation).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Soil temp.	0-10	0.59	35	17.485 + 1.120 X	4.21	< 0.01	34.2
	10-20	-0.04	35	20.166 – 0.233 X	-0.21	> 0.05	0
Soil moisture	0-10	0.37	35	33.314 + 2.112 X	2.29	< 0.05	13.4
	10-20	-0.17	35	31.129 – 2.570 X	-1.02	> 0.05	2.9
Bulk density	0-10	-0.37	35	1.163 – 0.015 X	-2.32	< 0.05	13.7
	10-20	0.09	35	1.210 + 0.011 X	0.56	> 0.05	0.1
Soil pH.	0-10	-0.01	35	5.554 + 0.002 X	0.04	> 0.05	0
	10-20	0.17	35	5.288 + 0.115 X	1.00	> 0.05	2.9

Table 88: Correlation and regression between Biomass of total earthworm and soil nutrients (Plantation).

Variable	Soil layers	r	df	Y	t	p	Variability (%)
Nitrogen (N)	0-10	0.37	35	294.953 – 12.614 X	2.31	< 0.05	13.6
	10-20	0.34	35	210.958 – 39.273 X	2.19	< 0.05	11.5
Phosphorus (P)	0-10	0.31	35	14.849 + 1.278 X	2.15	< 0.05	9.7
	10-20	0.05	35	14.357 + 0.357 X	0.29	> 0.05	0.2
Potassium (K)	0-10	-0.29	35	125.143 – 7.185 X	-2.14	< 0.05	11.01
	10-20	0.34	35	63.442 – 32.919 X	2.23	< 0.05	11.8
Carbon (C)	0-10	0.28	35	4.834 + 0.534 X	-2.39	< 0.05	15.1
	10-20	0.25	35	2.642 + 2.140 X	1.57	> 0.05	6.3

Chapter-VIII

COMMUNITY ANALYSIS

The community analysis was carried out on seven species of earthworms belonging to three families viz. Megascolecidae , Moniligastridae and Octochaetidae which were recorded during the sampling period in the three study sites of reserve forest, fallow and plantation ecosystems. Among the collected earthworms, Megascolecidae was represented by *Amynthas corticis*, *Amynthas* sp.1 and *Perionyx* sp., while the family Moniligastridae only had one species i.e. *Drawida* sp. whereas Octochaetidae was represented by *Eutyphoeus festivus*, *Eutyphoeus* sp.no.1 and *Eutyphoeus marmoreus*. As described above, only three earthworms were identified till the species level and the remaining four were identified only up to the genus level. Since all the three sites showed different physico-chemical properties of soil as well as microclimatic conditions, the species diversities and similarities of the communities were analyzed on the seven species by following the indices of Shannon Wiener (H′) (1949), Sorenson's index (Q/S) of similarity (1948), Margalef's index (Da) (1968) and evenness and equitability index, Pielou (1968).

While analyzing the earthworm communities in the three study sites using Shannon Wiener diversity index (H') and Margalef's index (Da), reserve forest ecosystem showed the maximum value of diversity with 1.66 (H') and 1.60 (Da) respectively. The value count in the fallow land was 1.32 (H') and 1.42 (Da) while the same was found to be the least with 1.21 (H') and 1.39 (Da) in the plantation ecosystems. The forest ecosystem was represented by the entire seven earthworm species recorded during the study period while in the remaining two sites, *Amynthas* sp.1was not recorded though the remaining six species were represented in varying numbers.

Similarly, the Hmax' or maximum diversity of earthworm species was also found to be highest in the reserve forest ecosystem with a recorded value of 1.94 while both the other two sites recorded same values of 1.79 each. The reserve forest ecosystem also recorded the highest evenness value (J') with 0.85 which was followed by the fallow land with 0.73 and plantation ecosystem with a value of 0.67 (**Table 89**). **Table 90** shows the diversity and Margalef's index values at different soil layers clearly indicating higher values at the top layers (0-10 cm) in reserve forest (1.52 and 1.61) and fallow land (1.13 and 1.43) but in the plantation, diversity index (H') was higher at 10-20 cm layer with 1.70. Hmax' values were also found to be higher in the topsoil layer in all the study sites.

The diversity (H') and Margalef's index (Da) in the reserve forest was found to be highest in the monsoon season with 1.73 and 1.77 respectively. The Hmax' value was highest in monsoon with 1.94 but evenness value (J') was highest in pre-monsoon with 0.89 (**Table 92 a.**). However, in the fallow ecosystem, though the diversity index (H') and Margalef's index (Da) values were higher with 1.29 and 1.56 in monsoon, interestingly the values were found to be high in the winter with 1.29 and 1.48 respectively as compared to pre-monsoon season. The Hmax' value was higher in the monsoon with 1.79 but the evenness (J') value was higher in the winter with 0.80. In the plantation ecosystem, Margalef's index was highest during winter with 1.74 followed by 1.53 in monsoon. But diversity (H') value was higher in monsoon with 1.29. The Hmax' value was highest in monsoon and winter with 1.79 each but the evenness (J') value was highest in pre-monsoon with 0.73. Correspondingly, similar analysis in different soil layers showed the same pattern with the topsoil layer (0-10) showing higher values of diversity index (H') and Margalef's index. Interestingly, the 10-20 cm soil layer in monsoon (reserve forest),pre-monsoon (fallow) and monsoon (plantation) showed the evenness (J') as 1.This was due to same earthworm species being encountered in the same soil layers at these sites (**Table 92 a,b,c**).

Seasonal species diversity of earthworm population in different soil layers i.e. at 0-10cm and 10-20cm have also been calculated for all the three study sites **(Table 91)**. The diversity indices in all the study sites have been recorded higher at 0-10 cm than 10-20 cm layers in different seasons. In reserve forest, both maximum and minimum diversity indices have been recorded at 0-10 and 10-20 cm during monsoon season only. While in fallow area H' and Da was maximum at 0-10 cm layer during monsoon and pre-monsoon season, plantation area recorded a maximum of H' and Da at 0-10 cm during the winter season. The Hmax' was recorded higher in monsoon season at 0-10 cm in all three sites; however, it was not recorded in fallow land at 10-20 cm layer during monsoon season. Evenness (J') among two soil layers did not show much significant variations in different sites. The forest ecosystem was represented by the entire seven earthworm species recorded during the study period while in the remaining two sites, *Amynthas* sp.1was not recorded though the remaining six species were represented in varying numbers. It can thus be conveniently concluded that the reserve forest ecosystem signifies more diversity **(Table 91).**

Community similarity of earthworms

Sorenson coefficient of community similarity index also known as the Quotient of similarity and Average Faunal Resemblance were calculated to study the similarity of earthworm community in the three study sites of reserve forest, fallow land and plantation (**Table 93-96**). The value of Sorenson Quotient (Q/S) and the average faunal resemblance between site II and site III was 100 % each respectively when seen at 0-10 cm soil layer as well as at 0-20 cm soil layer. The minimum value of Sorenson Quotient and the average faunal resemblance was found between site I and II with 92.30 % and 77.38% respectively. The values between sites I and III were 92.30 % and 85.71 % respectively. The result clearly shows that the earthworm communities exhibited optimum similarity between site II and III with the least similarity in the site I and II.

Community similarity and faunal resemblance of earthworm among the three sites in different seasons and soil layers is shown in **Table 95.** On a seasonal basis, the Sorensen's quotient of similarity of earthworm between site I and II have been recorded to be maximum at 0-10 cm (92.30%) and minimum at 10-20 cm (50%) during the rainy season. Between site I and III, similarity index was maximum (90%) at 0-10 cm during both winter and pre-monsoon season and minimum (80%) at 10-20 cm during the monsoon season. However, 100% species similarity was noticed at 0-10 cm during winter and 66.66% at 10-20 cm during monsoon season between site II and III. Between sites, I and II, the average faunal resemblance was recorded to be maximum at 0-10 cm (91.66%) during winter and pre-monsoon season and at 10-20 cm (75%) during pre-monsoon season. Between sites, I and III, maximum resemblance at 0-10 and 10-20 cm was noticed during winter (91.66%) and pre-monsoon (58.33%) season respectively. Similarly, 100% and 83.33% maximum earthworm resemblance was observed at 0-10 and 10-20 cm soil layer respectively during winter and pre-monsoon season. While on annual basis the Sorensen's quotient of similarity of earthworm have been recorded to be maximum and minimum in the soil layer of 0-10cm (100%) and 10-20 cm (75%) respectively between site II and III; the average faunal resemblance was maximum (100%) between site II and III at 0-10 cm and minimum (67%) between I and III at 10-20cm soil layer. The result clearly shows that the earthworm communities exhibited optimum similarity between site II and III with the least similarity in the site I and II. The degree of human interference and disturbances was found to be more or less similar in study sites II and III as compared to site I resulting in the optimal value in the two sites.

When observed seasonally, the Sorenson's coefficient and the faunal resemblance were optimum between sites I and II during the winter season (100 % each) and minimum between site II and III during winter (80 % each) at 0-20 cm layers (**Table 96**). At 0-10 soil layer, however, the values were optimum (100 % each) between sites II and III during the winter season and interestingly at 10-20 cm soil layer in the same season (winter), the Sorenson's coefficient and faunal resemblance values were minimum with 40 % and 41.66 % respectively (**Table 95**). The degree of human interference and disturbances was found to be more or less similar in study sites II and III as compared to the site I resulting in the optimal value in the two sites. However, variations in the values could be seen at 0-10 and 10-20 cm soil layers and during the different seasons in the study sites (**Table 95 & 96**).

The result from the present investigation indicates that species diversity and richness is much higher and consistent in reserve forest ecosystem at different soil layers and seasons due to the difference in their topography, vegetation with good canopy cover, rich litter, absence of biotic disturbance, microclimatic conditions that provide provided congenial physical habitat and trophic resource for earthworms (Lee,1985; Ruan *et al.,* 2005; Haokip and Singh, 2012) and stable ecosystems have high species diversity as compared to unstable environments (May, 1979). Singh (1997) reported the occurrence of 7 to 11 species from cultivated, non-cultivated, grassland, garden, and sewage soils. Kale and Seenappa (1997) observed a wider variant of species rather than species richness from sub-tropical and tropical regions. High species distribution and abundance of earthworm in reserve forest than fallow and plantation area is also due to optimum pH range, sufficient moisture content, water holding capacity and high amount of organic carbon and nutrient contents in soil (Sathianarayanan and Khan, 2006; Padmavathi, 2013). Bhadauria and Ramakrishna (1989) also reported that large scale destruction of forests has severely affected the diversity of earthworms. Ali Makin *et al*. (2014) also observed that diversity of earthworms is influenced by various factors such as type of soil, climates, the available organic resources, land use pattern and local disturbance. Studies on different land use system revealed a pattern of species diversity and richness having a record of 5-6 species in the foothills of Uttaranchal (Joshi and Aga, 2009), 3-5 species in the Punjab plains (Mohan *et. al.*, 2013), 4-7 species in Haryana plains (Sharma and Bhardwaj, 2014) and 2-8 species in the trans-Gangetic plains of Yamuna Nagar district in Haryana (Garg and Julka, 2017). Forest ecosystems usually had greater species diversity than anthropogenic habitats like pastures, cultivated and agroforestry systems (Fragoso *et. al.*, 1999) due to their complexity and availability of a variety of niches for earthworms to establish themselves (Edwards and Bohlen, 1996; Bartz *et. al.*, 2014). Tripathi and Bhardwaj (2004) observed the varied (H′) index value of earthworms in the different pedoecosystems of Jodhpur i.e. grassland (0), wasteland (0.670), garden (1.04), cultivated land (1.05) and sewage (1.06). The present finding of maximum diversity and evenness in reserve forest agreed with the observation of Garg & Julka (2017) who recorded the highest index of diversity and evenness (1.57 and 0.98) in *Shorea robusta* Forest and the indexes decreased to 1.54 and 0.79, 1.16 and 0.55, 0.63 and 0.91, 0.59 and 0.43, 0.41and 0.59 respectively in *Populus deltoides* plantation, home garden, herbal garden, cultivation and *Acacia catechu* forest from a study in a trans-Gangetic Plains of District Yamuna Nagar, Haryana. Thus, habitats with increasing complexity were considered most suitable for earthworm inhabitation and colonization (Whalen, 2004; Rahman *et al.,* 2011) from other parts of India and from elsewhere. Blanchart and Julka (1997) also reported high earthworm diversity in natural evergreen forest and low diversity in *Acacia* plantation of Western Ghat (South India). Cesarz *et al.* (2007) reported a positive correlation between earthworm diversity and tree species diversity indicating the importance of diverse food qualities for the decomposer fauna in natural forest. Several studies concluded that diversity of soil invertebrates increased from annuals crops to agroforestry systems to natural forest ecosystems (Fragoso and Lavelle, 1992; Blanchart and Julka, 1997; Rahman *et. al*., 2011; Bhadauria *et al*., 2014).Chaudhuri and Nath (2011) recorded higher Shannon diversity index in mixed forest (1.76) than rubber plantation (0.86) in Tripura. Haokip and Singh (2012) have also shown maximum species diversity and similarity in reserve forest than plantation and manage Oak forest ecosystem from Imphal, Manipur. The evenness (J′) analysis of the earthworm communities has also shown similar patterns of population distribution with the highest value 0.853 recorded in the reserve forest ecosystem, followed by fallow (0.739) and plantation (0.676) ecosystems respectively. The observation of H′ value of 1.66 in reserve forest, 1.320 in fallow and 1.212 in plantation area of present study sites is also in conformity with Suthar (2011) who observed variation of H′ value of earthworms from 1.543 (agricultural land) to 1.581 (tree plantation) to 1.586 (urban waste water drain soils) to 1.620 (moist soil) on different sites from semi-arid areas of Rajasthan, India and indicated that earthworms prefer moist environment of reserve forest not only for their survival but for species richness.

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Table 89: Table showing Shannon wiener's diversity index, Margalef's index, Hmax' and Evenness between the three study sites.

Sites	Margalef's index (Da)	Diversity (H')	Hmax'	Evenness (J')
Forest	1.60	1.66	1.94	0.85
Fallow	1.42	1.32	1.79	0.73
Plantation	1.39	1.21	1.79	0.67

Table 90: Table showing Shannon Wiener's Diversity index, Margalef's index, Hmax' and Evenness between the three study sites at different soil layers.

Sites	Soil Layer(cm)	Margalef's index (Da)	Diversity (H')	Hmax'	Evenness (J')
Forest	0-10	1.61	1.52	1.94	0.78
	10-20	1.17	1.08	1.38	0.78
Fallow	0-10	1.43	1.13	1.79	0.63
	10-20	1.00	0.86	1.09	0.78
Plantation	0-10	1.40	1.12	1.79	0.62
	10-20	1.70	1.08	1.60	0.67

Table 91: Table showing Shannon Wiener's Diversity index, Margalef's index, Hmax' and Evenness for different seasons in the three study sites.

	Seasons	Margalef's index (Da)	Diversity (H')	Hmax'	Evenness (J')
Forest	Winter	1.62	1.30	1.79	0.72
	Pre-monsoon	1.52	1.69	1.79	0.94
	Monsoon	1.77	1.73	1.94	0.89
Fallow	Winter	1.48	1.29	1.60	0.80
	Pre-monsoon	1.30	1.24	1.60	0.77
	Monsoon	1.56	1.29	1.79	0.72
Plantation	Winter	1.74	1.25	1.79	0.70
	Pre-monsoon	1.29	1.24	1.60	0.73
	Monsoon	1.53	1.29	1.79	0.66

Table 92: Table showing Shannon Wiener's Diversity index, Margalef's index, Hmax' and Evenness for different seasons in the three study sites at different soil layers.

a) Reserve forest ecosystem

Seasons	Soil Layer(cm)	Margalef's index (Da)	Diversity (H')	Hmax'	Evenness (J')
Winter	0-10	1.62	1.27	1.79	0.71
	10-20	1.31	0.73	1.09	0.66
Pre-monsoon	0-10	1.55	1.68	1.79	0.94
	10-20	1.21	1.22	1.38	0.88
Monsoon	0-10	1.77	1.73	1.94	0.89
	10-20	0.74	0.69	0.69	1

b) Fallow land ecosystem

Seasons	Soil Layer(cm)	Margalef's index (Da)	Diversity (H')	Hmax'	Evenness (J')
Winter	0-10	1.50	1.31	1.60	0.81
	10-20	0.65	0.63	0.69	0.91
Pre-monsoon	0-10	1.23	1.60	0.76	1.30
	10-20	0.60	0.69	0.69	1
Monsoon	0-10	1.57	1.30	1.79	0.72
	10-20	NR	NR	NR	NR

c) Plantation ecosystem

Seasons	Soil Layer(cm)	Margalef's index (Da)	Diversity (H')	Hmax'	Evenness (J')
Winter	0-10	1.74	1.21	1.60	0.75
	10-20	1.14	0.62	1.09	0.57
Pre-monsoon	0-10	1.29	1.20	1.60	0.74
	10-20	0.92	0.91	1.09	0.82
Monsoon	0-10	1.53	1.18	1.79	0.66
	10-20	0.74	0.69	0.69	1

Table 93: Showing the annual similarity of earthworms in different soil layers of sites I, II and III.

Sites	soil layers (cm)	Seasons	Sorenson's coefficient (Q/S) (%)	Average Faunal Resemblance (%)
I and II	0-10	annual	92.3	92.85
	10-20	annual	85.71	87.5
I and III	0-10	annual	92.30	92.85
	10-20	annual	88.88	67.5
II and III	0-10	annual	100	100
	10-20	annual	75	80

Table 94: Showing the annual similarity of earthworms in sites I, II and III.

Sites	soil layers (cm)	Seasons	Sorenson's coefficient (Q/S) (%)	Average Faunal Resemblance (%)
I and II	0-20	annual	92.30	77.38
I and III	0-20	annual	92.30	85.71
II and III	0-20	annual	100	100

Table 95: Showing the similarity of earthworms in different seasons and soil layers of site I, II and III.

Sites	soil layers (cm)	Seasons	Sorenson's coefficient (Q/S) (%)	Average Faunal Resemblance (%)
I and II	0-10	Winter	90.90	91.66
		Pre-monsoon	90.90	91.66
		Monsoon	92.30	77.38
	10-20	Winter	66.66	37.5
		Pre-monsoon	66.66	75
		Monsoon	50	37.5
I and III	0-10	Winter	90.90	91.66
		Pre-monsoon	90.90	73.33
		Monsoon	83.33	85.71
	10-20	Winter	66.66	29.16
		Pre-monsoon	85.71	58.33
		Monsoon	80	41.66
II and III	0-10	Winter	100	100
		Pre-monsoon	80	80
		Monsoon	90.90	91.66
	10-20	Winter	40	41.66
		Pre-monsoon	80	83.33
		Monsoon	66.66	75

Table 96: Showing the similarity of earthworms in different seasons of site I, II and III.

Sites	soil layers (cm)	Seasons	Sorenson's coefficient (Q/S) (%)	Average Faunal Resemblance (%)
I and II	0-20	Winter	90.90	91.66
		Pre-monsoon	90.90	91.66
		Monsoon	92.30	92.85
I and III	0-20	Winter	100	100
		Pre-monsoon	90.90	91.66
		Monsoon	83.33	85.71
II and III	0-20	Winter	90.90	91.66
		Pre-monsoon	80	80
		Monsoon	90.90	91.66

Chapter-IX

EFFECT OF EARTHWORM ON PLANT GROWTH

Being considered as ecosystem engineers, earthworms play an important role in the improvement of soil physical structure, soil fertility, organic matter dynamics, nutrient cycling rates and plant growth through their peculiar feeding, burrowing and casting activities (Edwards and Bohlen, 1996). Syers *et al.* (1984) have demonstrated that lumbricid earthworms from temperate regions are capable of stimulating plant growth in grasslands. Earthworm plays a vital role in the formation and maintenance of fertile soils and is thus paramount for sustainable primary production and waste management (Blakemore and Paoletti, 2006). Samaranayake and Wijekoon (2010) observed that earthworm activity not only increase in plant nutrients but also improve the physical and biological nature of the soil.

Quite a few reports on beneficial effects of earthworm on incorporation of organic matter, improving availability of plant nutrients in soil, increase in plant growth and yield are available from different part of the world (Edward *et al.,* 1990; Devliegher and Verstraete, 1997; Brown *et al.*, 1999; Wardle, 2002; Tuffen *et al.,* 2002; Mayilswami and Reid, 2010; Khomami and Zadeh, 2013 and Palacios *et al.,* 2014). Further, considerable evidence are also available to show that introduction of earthworm through pot trial experiments increase plant growth of wheat (van Rhee, 1965), oat plants (Altavinyte and Pociene, 1973), barley plants (Temirov and Valiakhmedov, 1988), maize (Spain *et al*., 1992), wheat seedlings and wheat grain yield (Stephens *et al*., 1994; Baker *et al*., 1995; Stephens and Davoren, 1995). Recently, Dalakoti (2015) observed positive effect *Metaphire posthuma* on plant growth of wheat and maize from Kumaun Himalaya.

With a view to see the effect of Earthworm on plant growth under Nagaland climatic condition, *Eutyphoeus festivus,* the endogeic species was selected based on its abundance and dominance among the species recorded from the three study sites. The earthworm used in the experiment was taken directly from the field. Moreover, *Eutyphoeus festivus* was easier to handle in the laboratory. Two treatments were applied: a) “Control treatment” without earthworms, (b) a plus “earthworm’s treatment” with 5 matured individuals of *Eutyphoeus festivus* (clitellates) with an average fresh weight between 4.18 to 6.23 g per pot. The experiment was run in 3 replicates each for both “control” and “soil + earthworms”. Earthworm fresh biomass was determined before and after the experiment. Earthen pots (26 cm diameter, 20 cm deep) were filled with normal wet field soil.

All pots were maintained at 20-25 °C (corresponding to the atmospheric temperature) and soil moisture of 25-30% for three months (watering every alternate day). The simple test experiment was done on the maize crop. Five seeds of maize were sown per pot. Pots were regularly irrigated to balance the moisture content and plants were thinned to two per pot after about a couple of weeks later and were subsequently left with only one healthy plant after about 5 weeks. The experiment lasted three months wherein comparative study of the two i.e. “soil + earthworms” pots and “control “pots were done. The plants were harvested after maturity which was approximately three months (90 days) from the date of sowing. The plants were removed from the pots and dried at 60 °C for 24 hours after the fresh weights were taken so as to determine the dry weights also. Shoots, roots and cobs of each plant were weighed separately. The length of shoots, roots and fruits were also measured independently.

The maize crop result for the “soil + earthworm treatment”, showed an increase of 19.04 % in root length, 22.33% in shoots length, 25.88% in root weight and 36.13% in cob weight as compared to that of control**.** Pod length and weight of shoot besides being healthier, was also higher (39.81% and 31.45% respectively) for the “soil + earthworm treatment” as compared to the control **(Table 97)**. Plant growth seemed to be considerably influenced by the presence of earthworms. There was an increased dry mass of the root and shoot in comparison to that of "Control".

The potassium and phosphorus availability in the 'control' and 'soil + earthworm' pots showed an increase of 10.82% and 10.86% respectively indicating a presence of more soil nutrient with earthworms. The available nitrogen also showed an increase of 5.39% in the pots containing earthworms **(Table 98)**. The organic carbon also exhibited a higher presence in the soil with earthworms i.e. 7.27% higher than in the soil of 'control' pots. Thus by enhancing nutrient availability and improving soil physical properties, earthworms increase plant growth (Lee, 1985; Baker *et al.,* 1999). Dalakoti (2015) observed that earthworm not only increases soil chemical fertility as a result of the incorporation of organic matter but that nutrients are also made available during gut transit, thereby showing the positive impact on plant growth. The effect of macrofauna population in the soil on improved production of tea is evidently elucidated by Senapati *et al*. (1994, 1999, and 2001). However, Mackay and Kladivko (1985) could not show any change in the roots and shoots of maize plant while managing it with earthworm populations. They argued that the nutrient and structural state of the soil used in the experiment was adequate to dominate any supplementary effects the earthworms might have had.

Interaction between earthworms and microorganisms provide the nutrients which ultimately stimulate plant growth indirectly in several other ways (Lavelle and Martin 1992). Samaranayake and Wijekoon (2010) recorded the significant positive effect of *P. corethrurus* earthworms on the growth of maize which is likely due to a combination of interacting factors such as accumulations of earthworm casts rich in C/N, soil aeration due to earthworm movement within the root zone of the soil. Further optimum yield enhancement is achieved by a population increase of earthworm by management through production of components which are utilized by the growing roots and also enhancing the release of nutrients in synchrony with the demands of the plants (Spain *et al.,* 1992; Fragoso *et al.,* 1997). Thus it can be concluded that *Eutyphoeus festivus* as one of the dominant species has great impact on plant development primarily by increasing the availability of nutrients from the overall nutrient pool (Baker *et al*., 2006), by altering microorganism and soil invertebrate communities (Scullion and Malik 2000), and also by altering the structure as well as the chemical composition of soil (Bottinelli *et al*., 2015).

Table 97: Production of shoots and roots (g dry mass) and shoot length (cm) for maize crop, with or without earthworms inoculation after 90 days of growth (n=5, mean ± SE).

Parameters	Soil +Earthworms	Control (No worms)
Root Length (cm)	23.1 ± 4.4	18.7
Shoot Length (cm)	110.3 ± 1.69	85.66
Pod Length (cm)	12.13 ± 1.02	7.3
Weight of root (g)	6.76 ± 1.03	5.01
Weight of shoot (g)	50.11 ± 1.63	34.35
Weight of Pod (g)	8.91 ± 0.89	5.69

Table 98: Comparative results of soil nutrients in the 'control' pots and 'soil + earthworms' pots.

S.No.	Available nitrogen(kg/ha)		Potassium (kg/ha)		Phosphorus (kg/ha)		Organic carbon (%)	
	control	Soil+ earthworms	control	Soil+ earthworms	control	Soil+ earthworms	control	Soil+ earthworms
1	316.32	326.00	119.23	130.03	18.11	20.49	2.22	2.49
2	240.42	250.77	84.21	97.25	17.02	18.54	1.78	1.88
3	278.12	305.67	107.13	120.96	19.78	22.56	2.14	2.23

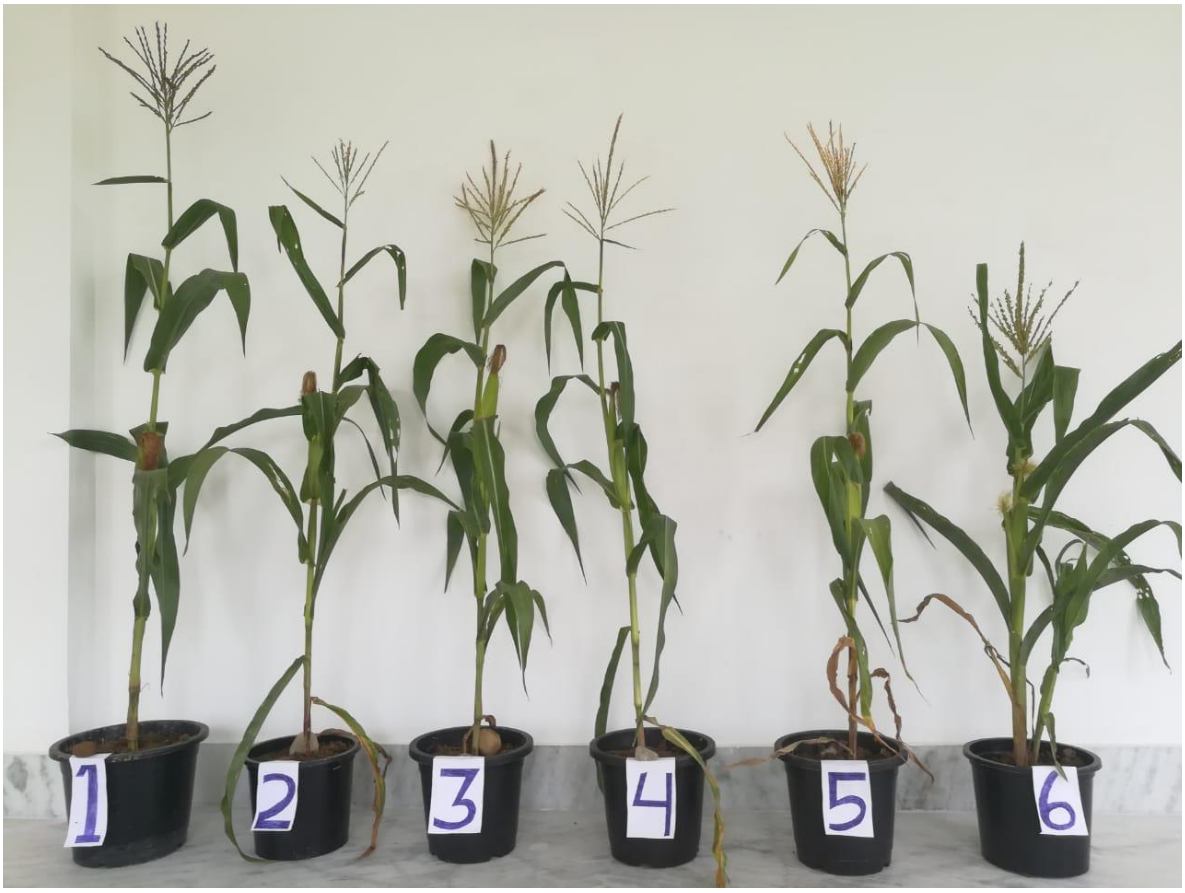

Plate 16: Plant growth experiment with maize.

(a)

(b)

Plate 17: Root growth showing difference between (a) plus earthworm (increased length) and (b) Control (decreased length).

Chapter-X

SUMMARY AND CONCLUSIONS

The present study was carried out in three different sites of a contiguous sub-tropical hill forest ecosystem characterized with gentle to steep slopes viz. reserve forest, fallow area and plantation area respectively located in Mingkong area which is about 10 km away from Mokokchung town. These sites lie at 29° 15'-30° 15' North latitude and 77° 55'-78° 30' East longitude and the altitude ranges from 1400 to 1600 m above MSL. The reserve forest site comprises of rich vegetation with tropical semi-evergreen type with diverse tree species, herbaceous ground vegetation, different climbers, common banana trees, epiphytes, ground flora like fern, bryophytes, lichens etc. and free from human interference. Fallow land is about 5 years old vegetation left over after slash and burn (Jhum) cultivation and mainly dominated by different types of herbs, shrubs, grasses, climbers and scattered not very tall trees. Plantation area is comprised of *Gmelina arborea* (monoculture) with certain grass and banana species. The sampling was done from November 2014 to October 2015.

Earthworms and soil were collected monthly from 0-10 and 10-20 cm soil layer from each site at different elevation taking a total of 81 plots in each month. They were hand sorted, brought to the laboratory, washed, weighed and straightened which were then preserved in 4% formalin for further taxonomic identification. Soil samples were analysed for soil temperature, soil moisture, bulk density, soil pH, Organic carbon, Available nitrogen, available phosphorus, potassium. Appropriate statistical tools are used for community analysis of earthworms.

A total of seven species of earthworms belonging to three families *viz.* Megascolecidae , Moniligastridae and Octochaetidae were recorded during the sampling period in the three study sites of reserve forest, fallow and plantation ecosystems. The three species of Megascolecidae included *Amynthas corticis*, *Amynthas* sp.1 and *Perionyx* sp., while Moniligastridae, was represented only by *Drawida* sp. and Octochaetidae was represented by *Eutyphoeus festivus*, *Eutyphoes* sp.no.1 and *Eutyphoeus marmoreus*. Of the seven species, *Amynthas* sp.1 was collected only from the reserve forest ecosystem while all the other six species were found to be present in all the three sites.

Of the three ecosystems, reserve forest recorded the highest earthworm population density with 609.68 Nos. m^{-2} followed by plantation (386.1 Nos. m^{-2}) and fallow (356.56 Nos. m^{-2}) respectively. However, for biomass, it showed a slightly different pattern. Though forest site recorded the highest total biomass (549.87 g m^{-2}), it was followed by fallow land with 254.58 g m^{-2} and plantation 216.60 g m^{-2} respectively. As compared to reserve forest, reduction of 41.52% density and 53.71 % biomass in fallow ecosystem and reduction of 36.68 % density and 60.61 % biomass in the plantation ecosystem respectively was evident. There was a difference of 7.66 % and 14.92 % of density and biomass respectively between site II and site III. Good canopy cover of reserve forest along with the thick presence of herbs, shrubs; and the least biotic disturbances maintains optimum condition for accumulation of soil nitrogen, organic carbon, moisture content and temperature account for higher aggregation of earthworms

Variation in earthworms in three different sites and seasons is generally influenced by a combination of many ecological parameters of which the two major factors are soil temperature and moisture. Population density of total earthworms was more abundant in the monsoon season (257.71 Nos. m^{-2}) which was followed by the pre-monsoon (221.22 Nos. m^{-2}) and winter (130.76 Nos. m^{-2}) seasons in the reserve forest ecosystem. However, biomass recorded the maximum in pre-monsoon (239.33 g m^{-2}), followed by monsoon (224.04 g m^{-2}), and winter (77.62 g m^{-2}). In the fallow ecosystem, monsoon recorded the maximum of both density and biomass (173.48 Nos. m^{-2} and 138.24 g m^{-2}) which was followed by pre-monsoon (121.01 Nos. m^{-2} and 97.97 g m^{-2}) and winter (53.84 Nos. m^{-2} and 18.34 g m^{-2}) respectively. Similarly, in plantation site, population density and biomass of total earthworm was maximum in monsoon (195.59 Nos. m^{-2} and 96.23 g m^{-2}) followed by pre-monsoon (139.27 Nos.m^{-2} and 85.2 g m^{-2}) and winter (80.64 Nos. m^{-2} and 35.17 g m^{-2}) seasons.

Monthly variation showed that in the reserve forest ecosystem, total earthworm population density at 0-10 cm showed a maximum in the month of September (88 Nos. m^{-2}) and minimum in the month of December (22 Nos. m^{-2}). In the fallow ecosystem, total earthworm population fluctuation indicated peak month in September (64.76 Nos. m^{-2}) at 10-20 cm soil layer. While in plantation, the total earthworm population at 0-10 cm layer was highest in the month of August with 57.43 Nos. m^{-2} and the least was in December with 13.43 Nos. m^{-2}. Different factors both physical and edaphic at deeper soil layer may be unsuitable which result for less earthworm density. But in case of upper layer soil due to the constant deposit of decay materials may be one of the contributions for more young and immature stages as well as adults group. The result from the analysis of variance (ANOVA) at different soil layers showed significant differences between the seasons.

The monthly variation of total biomass exhibited the highest biomass in the month of May with (112.75 g m^{-2}) for the reserve forest while December recorded the least biomass count of only 12.01 g m^{-2}. In the fallow ecosystem, biomass was highest in September with 60.72 g m^{-2} and least in January with 1.21 g m^{-2}. In the plantation ecosystem though, September recorded the highest biomass count with 32.64 g m^{-2} and February recorded the minimum with 4.89 g m^{-2} at 10-20 cm soil layer. The distribution pattern in density and biomass of the individual species also followed a similar trend.

All the epigeic, endogeic and anecic species were found to be maximum during the months of the monsoon season. *Perionyx* sp. was the most dominant species among the epigeic species followed by *Amynthas corticis* and *Amynthas* sp.1. *Eutyphoeus festivus* and *Eutyphoeus* sp.no.1 were found to be the dominant species among the endogeic species.

The lone representative of anecic species i.e. *Drawida* sp. was also found to be highest during the monsoon seasons. In the present investigation, the soil moisture content in the top layer was found to be always higher than in the lower soil layers because of which earthworm density showed a decreasing trend as the soil depth increased in all the study sites. Beyond 20 cm soil layer, no earthworms could be recorded perhaps due to decreasing moisture content with increasing depth. The soil temperature was in the range of 10.1ºC-18.1ºC in the reserve forest, 15.31 ºC -19.82 ºC in the fallow and 13.85 ºC - 20.91 ºC in the plantation sites. In the present investigation, the pH ranged from 4.53 to 6.23 which indicated that soil in all the sites was acidic in nature and hence the earthworms encountered may be rightly termed acid tolerant species. In the present study, soil nitrogen content demonstrated a positive significant relationship with total earthworm density in all the three sites, viz. the reserve forest ($r = 0.35$, $P < 0.05$), fallow ($r = 0.40$, $P < 0.05$) and plantation($r = 0.37$, $P < 0.05$) ecosystems respectively.

Vertical distribution of earthworms showed a steep decline in population with an increase in soil depth having no record beyond 20 cm soil layer in all the three study sites. Total density and biomass in reserve forest were recorded 566.92 Nos. m^{-2} and 479.24 g^{-2} at 0-10 cm soil layer contributing 92.98 % and 87.15 % respectively to the total earthworm biomass. In the fallow ecosystem, the total earthworm density at 0-10 cm soil layer was 345.98 Nos. m^{-2} and biomass was 244.71 g^{-2} which contributed to 96.91% and 96.12% to the total earthworm density and biomass respectively. In the plantation ecosystem, the total earthworm density was 358.18 Nos. m^{-2} contributing 92.76% to the total earthworm collected and biomass was 198.73 g^{-2} contributing 91.74% to the total earthworm biomass collected in the same layer. This clearly indicated that earthworms prefer the topsoil layer for its sustenance. At the species level, individual species like *Drawida* sp. exhibited 89.52%, 96.88% and 92.22% at the top soil layer in the reserve forest ecosystem (site I), fallow (site II) and plantation (site III) ecosystem respectively. *Amynthas corticis* showed 100% presence in the topsoil layer 0-10 cm in all the three sites. *Perionyx* sp. and *Eutyphoeus marmoreus* also showed 100% in the topsoil layer in the fallow site. *Eutyphoeus festivus* exhibited 90.84%, 96.94% and 93.29% in the topsoil layer at the site I, site II and site III respectively.

Monthly variation of total earthworm variation in the reserve forest ecosystem varied from 23 Nos. m^{-2} to 88 Nos. m^{-2} and 12 g m^{-2} to 112 g m^{-2} respectively. In the fallow ecosystem, it varied from 6 Nos. m^{-2} to 64 Nos. m^{-2} and 1 g m^{-2} to 61 g m^{-2} and in the plantation ecosystem, it ranged from 13 Nos. m^{-2} to 58 Nos. m^{-2} and 5 Nos. m^{-2} to 33 Nos. m^{-2}.While different physico-chemical factors particularly soil moisture, soil temperature, organic carbon and nitrogen show positive and negative correlation with total earthworms and certain individual species at different soil layers, it was synergic and cumulative effect of various parameters including climatic regime rather than the single factor that affect the population size of the earthworm from time to time.

The annual species diversity in the reserve forest ecosystem was (1.660) which was comparatively higher than the Fallow (1.320) and plantation (1.212) as revealed from the Shannon-Wiener Index. The evenness (J′) analysis of the earthworm communities has also shown similar patterns of population distribution with the highest value 0.853 recorded in the reserve forest ecosystem, followed by fallow (0.739) and plantation (0.676) ecosystems respectively. The H′max values were shown to be higher during the monsoon season (1.945), followed by 1.791 and 1.791 during the winter and pre-monsoon seasons respectively in the reserve forest. A similar trend was observed in the fallow as well as plantation sites.

The maize crop result for the “soil + earthworm treatment”, showed an increase of 19.04 % in root length, 22.33% in shoots length, 25.88% in root weight and 36.13% in cob weight as compared to that of control. Pod length and weight of shoot besides being healthier, was also higher (39.81% and 31.45% respectively) for the "soil + earthworm treatment" as compared to the control. There was an increased dry mass of the root and shoot in comparison to that of "Control".

The potassium and phosphorus availability in the 'control' and 'soil + earthworm' pots showed a steady increase of 10.82% and 10.86% respectively while available nitrogen also showed a hike of 5.39% in the pots containing earthworms. The organic carbon exhibited a higher presence in the soil with earthworms' i.e., 7.27% higher than in the soil of 'control' pots.

It can thus be concluded from the present investigation that:

1) Population density and biomass of earthworm is maximum in reserve forest followed by plantation and fallow ecosystem.
2) Higher abundance of earthworms during monsoon season is related to the availability of food and higher reproduction due to the optimum condition of soil temperature, moisture, organic carbon and available nitrogen.
3) Differences in the microclimatic conditions of the soil combined with the different physico-chemical factors of soil at 0-10 cm and 10-20 cm, and also the soil nutrients appear to be key factors in the earthworm distribution.
4) *Eutyphoes festivus* not only enhances soil chemical fertility due to the incorporation of organic matter but that nutrients are also made available to plants for its development.
5) It is emphasized that no single factor but the cumulative factors with synergic effects were responsible for the distribution and diversity of earthworms which also play a very important role in soil alteration and their subsequent mineralization.

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