ECOLOGICAL STUDIES ON EARTHWORM POPULATION IN AGROFORESTRY SYSTEM OF MIZORAM

by

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I, Mr. **H. Lalthanzara**, hereby declare that the subject matter of this thesis entitled "*Ecological studies on earthworm population in agroforestry system of Mizoram*" is the record of the work done by me, that the contents of this thesis did not form basis of the award of any previous degree or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University / Institute.

This is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Forestry.

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List of Abbreviations

NA	=	not available
PCL	=	Pineapple + Citrus + *Leucaena*
ML	=	Maize + *Leucaena*
CTRL	=	Control
NPK	=	Nitrogen Phosphorus Potassium
et al.	=	*et alii*: and others
etc.	=	et cetera: and the others
g/gms	=	gram(s)
ml	=	milliliter
ha	=	hectare
Ed:ed(s)	=	Edition : editor(s) or edited
^{o}C	=	Degree Celsius
sp.	=	species
WHC	=	water holding capacity
SEM	=	standard error of mean
SD	=	standard deviation
P	=	available phosphorus
K	=	available potassium
OC	=	organic carbon
N	=	total nitrogen
Db	=	Bulk density
SKT	=	Sakawrtuichhun (expertimental site)
PUC	=	P.U. College (experimental site)

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Chapter 1
Introduction

Earthworms are the large megadrile annelids of the class Oligochaeta which constitute more than 80% of the soil invertebrate biomass in many ecosystems (Nainawat and Negendra, 2001). Earthworms are the major group of soil invertebrates in subtropical and tropical as well as in temperate zones (Kale, 1997). Earthworms are classified into detrivores and geophagous based on their feeding habit. Detrivores consists of epigeic and anecic which feed on surface litter or other organic matter and geophagous are endogeic.

1.1. Beneficial functions:

Earthworms perform several beneficial functions which include:

Decomposition and nutrient release

Many microorganisms are responsible for decomposition of organic matter that eventually reaches the soil. Not all plant material is subjected to immediate decomposition by soil microorganisms. Some plant materials are broken up and made into smaller pieces by other soil fauna. The soil harbours a large number of worms and insects. Soil fauna are the subsidiary source of organic matter. When they consume plants as their feed, they excrete their waste products as casts. Earthworms break up larger plant organic matter by their feeding activities. Their feeding and burrowing activities incorporate organic residues to the soil which in turn enhance decomposition, humus formation, nutrient cycling and soil structural development (Mackay and Kladivko, 1985; Kladivko *et al.,* 1986). Thus earthworm plays important role in the translocation of plant residue and also helps in decomposition. Quality, quantity and placement of organic matter are the main determinants of earthworm abundance and activity in agricultural field (Edwards, 1983; Lofs-Holmin, 1983a), as are disturbances of the soil by tillage, cultivation and the use of pesticides (Doran and Werner, 1990).

Mixing and castings

Earthworms feed on plant litter as well as a wide range of decaying organic substances. An earthworm consumes plant litter, dung or manure, and other organic materials from the upper horizon and transmits to lower horizon of the soil, and form castings within and above the surface of the soil. Charles Darwin (1881) calculated that earthworms could move large amounts of soil from the lower layers of the earth to the surface and also carry organic matter down into the deeper soil layers. Soil from the subsoil horizon is moved by these animals to the upper levels where it is mixed with the surface soil, resulting in a more uniform distribution of plant nutrients. A large proportion of soil passes through the guts of earthworms, and they can turn over the top six inches (15 cm) of soil in ten to twenty years. Earthworms consume organic matter and mineral particles and excrete wastes in the form of casts. Earthworm casts are masses of mineral soil often mixed with smaller bits of digested plant residues. Earthworm that lives in horizontal burrows, select the food from within the soil, deposit casts within their burrows or in other spaces within the soil. Earthworms that make vertical burrows that open to the soil surface often feed on organic materials that are on the upper horizon of the soil surface and deposit castings on the soil surface. Earthworm activities of eating, burrowing, mixing and casting helps in formation of soil aggregates, aeration of the soil improving soil water infiltration and water holding capacity, that ultimately improves soil structure.

Increased air and water infiltration

Earthworms improve the soil aeration by their burrowing activity and soil porosity by improving the overall structure of the soil as a habitat for themselves and other soil organisms. Earthworm enhances porosity in the soil by creating macropore. This allows water to soak into the soil more easily (Zachmann and Linden, 1989; Kladivko and Timmenga, 1990). Some species make permanent burrows deep into the soil. These burrows can persist longer period even after the death of earthworm and helps in retention of soil moisture, particularly under heavy rainfall area. The channels made by deep-burrowing earthworms are lined with readily available nutrients. This facilitates growth of roots deep into the soil.

Aggregates

The particles referred to as sand, silt and clay occur in soil in the form of aggregates. The arrangement of the individual soil particles and their aggregates in a particular manner is called soil structure. The individual soil particles are joined into groups which are known as soil aggregates. Soil aggregates stability is another point which deserves attention. Aggregate stability is directly correlated to the presence or absence of certain binding agents. Organic compounds, some clay minerals, iron oxide etc., affect the stability of aggregates. Secretions in earthworm intestines cement soil particles together into aggregates which also aid in erosion control (Ramsay and Hill, 1978). A soil that is rich in aggregates is well aerated and drained. Scientists have agreed that earthworm casts contain more stable aggregates than other soil. However, earthworms are not essential to the process of forming soil aggregates because the activity of other soil organisms including bacteria and fungi can also stabilize soil aggregates (Brady and Weil, 2002).

Increase the availability of plant nutrients

Earthworms play important role in breakdown (through ingestion) as well as to subsequent decomposition of organic matter. In fact, earthworms may consume more surface organic matter than all other soil fauna together. Nutrient rich earthworm casts are more water-soluble and available to plants (Ramsay and Hill, 1978). Researchers have found that worm casts are generally richer in exchangeable calcium, potassium, and phosphorus than the surrounding soil, while earthworms themselves and their excretions are valuable sources of nitrogen. Earthworms counteract the effects of leaching by bringing soil nutrients to the upper horizons from the lower subsoil (Sharpley and Syers, 1976; Mansell *et al.,* 1981; Krishnamoorthy, 1990; Bohlen and Edwards, 1995; Hauser and Asawalam, 1998; Sculion *et al.,* 2002; Norgrove *et al.,* 2003; Asawalam, 2006 and Kuczak *et al.,* 2006).

1.2. Distribution and Diversity:

Earthworms are found on almost all types of soils and different climatic zones except in arctic and sandy deserts. Studies on the population dynamics of earthworm in Meghalaya demonstrated that the earthworm population increases during or late rainy period and a decline in population size during the dry winter months (Bhadauria and Ramakrishnan, 1989). Earthworms are not distributed randomly in soil. Soil type mainly determines earthworm community composition at the scale of soil type patches. Earthworms may be absent or rare in soils with coarse texture probably due to the susceptibility to drought of such soils (Lee, 1985). The minimum moisture level for their activity is the level required for growth of most plants. There is an interspecific earthworm association which also affects distribution of earthworms in a particular microhabitat (Krishnamoorthy and Ramachandra, 1988). Temperature may be a factor of primary importance in determining the distribution, composition and structure of earthworm communities (Lavelle 1983a; Lavelle *et al*., 1989). Baker (1998) has demonstrated the importance of soil moisture content in determining earthworm distribution and activity. Soil moisture affects earthworm abundance, activity patterns and geographic distribution (Evans and Guild, 1947; James, 2000). The distribution of earthworms was mainly dependent on the physico-chemical characteristics of the soil. Soil pH is a limiting factor on earthworm distribution. Earthworms are generally absent from very acid soils (pH < 3.5) (Curry, 1998). Moisture and available organic matter are also considered as important limiting factors for earthworm distribution. Carbon/Nitrogen ratio is a measure of litter degradation in soils and it governs the diversity and abundance of earthworms. Earthworms prefer materials with a low C/N ratio to a higher C/N ratio (Ruz Jerez *et al.,* 1988).

Exhaustive literature is available on the biodiversity of earthworms from temperate regions such as Australia and Africa. But comparatively the study on the biodiversity of earthworms in Indian subcontinent is negligible. Systematic studies on the earthworms of the Indian subcontinent were initiated in 1844 by Templeton (Julka, 1988). The pioneering work of Stephenson (1923) and Gates (1972) gives a brief picture of distribution of earthworms in South East Asia and Indo-Gangetic plains. Julka and Senapati (1987) have given detailed distribution of earthworms of Orissa. Ismail (1997) reported species richness and diversity in selected ecological niches in Madras city. Kale (1997) has described the earthworm faunal diversity in relation to three major geographical regions of Karnataka. Chanda *et al*. (2003) have described 17 species of earthworm from Midnapore district of West Bengal. Sporadic reports are available on the earthworms of N.E. region of India. It includes the work on earthworms of Tripura (Chaudhuri and Bhattacharjee, 1999) and earthworms of Meghalaya (Mishra and Ramakrishnan, 1988; Halder, 1999). Inventory studies have shown 5 species of earthworms from agroforestry systems of Mizoram (Ramanujam *et al*., 2000).

1.3. Population structure:

Earthworm population structure is influenced by land use pattern. The species richness is affected by various factors. Type of vegetation is major biotic factor which determines the distribution and diversity of earthworms. Physico-chemical characteristics of the soil which may be the result of different land use patterns or independent of it significantly influence the earthworm population structure. Slash and burn cultivation (Jhuming) tends to have a negative effect on earthworms population size (Springett *et al.,* 1992; Fraser, 1994). Regular weeding is supposed to have a negative influence on earthworm population. Agricultural practices had a stronger impact on earthworm community structure at the scale of the agricultural plot (Decaëns *et al.,* 2004). Annual crops are relatively unfavourable systems for soil macrofauna, and in general have low earthworm biomass (Lee, 1985). Ploughing is known to have a negative effect on earthworm population (Wyn and Glanteller, 1992). The changes in soil properties as a result of deforestation directly altered the earthworm communities and its population structure (Dotson and Kalisz, 1989; Bhadauria *et al*., 1997; Blanchart and Julka, 1997). Earthworm population size has been significantly correlated with soil moisture, temperature and organic matter (Bhadauria and Ramakrisnan, 1989).

1.4. Earthworm biomass:

The biomass of earthworm is significantly correlated with soil organic matter (Springett *at al.,* 1998). The species and density of earthworms determine the biomass. The type of vegetation may also have effect on earthworm biomass. The seasonal dynamics over an annual cycle have shown that the earthworm biomass was high in the rainy and early winter season and low in summer (Bhadauria and Ramakrishnan, 1989; Kaushal and Bisht, 1994). It reached maximum in the month of September and was negligible in winter months with minimum in February.

1.5. Secondary productivity:

Secondary productivity refers to the net quantity of energy transferred and stored in the somatic and reproductive tissues of heterotrophs over a period of time. It is of great importance, since it serves as an index of significance of the population in terms of food resources available to the heterotrophic populations, including man, in the food chain. Secondary productivity of earthworm is determined by type of earthworm species, density and biomass along with the type of vegetation. Earthworm secondary productivity was recorded higher in manure treatment than in inorganic fertilizer treatment (Whalen and Parmelee, 2000). Estimates of earthworm community secondary production can quantify the direct role of earthworms in the C and N cycle (Parmelee and Crossley, 1988). Dash *et al.* (1974) observed that the ratio of secondary production to the average biomass (population biomass turnover) was around 4.5 for Oligochaetes of Behrampur.

1.6. Worm cast as bio-fertilizer:

Worm casts are collected mainly in the rainy season. Worm cast shows higher moisture content, pH, organic carbon and inorganic nutrients like phosphorus, potassium and nitrogen compared to adjacent soil. Worm cast is also rich in humus forming microbes and nitrogen fixers and the drying of the cast does not deteriorate the microbial population (Bano *et al.,* 1987, Simek and Pizl, 1989). Therefore, these characteristics qualify the worm cast as bio-fertilizer.

Inorganic fertilizers have played a pivotal role in modern agriculture. Increased use of fertilizers to boost the productivity is reported to influence the population density of earthworms. Both beneficial and harmful effects have been reported by various workers (Reddy and Ground, 1987; Brussard and Ridder, 1990; Sahu *et al.,* 1995).

1.7. Major cropping systems in Mizoram:

Shifting agriculture or slash-and-burn agriculture locally referred as ‘Jhum’ is an age old farming practice followed by Mizos and farmers in the hill region of north-eastern States. With increase in population and higher demand for agricultural crops the jhum cycle has been reduced to the interval of 3 - 4 years which has lead to ecological imbalance. Introduction of new models of agroforestry are being tried as an alternative for jhum cultivation or to rehabilate degraded hills (Jha, 2000). The agroforestry model conserve soil, moisture and nutrient maintaining the sustainability of degraded hill slope or degraded jhum land.

Agroforestry can be best defined as a land use system that involves deliberate retention, introduction of mixture of trees or other woody perennials in crops / animal production, to benefit from the resultant ecological and economic intersections (Nair, 1984). Agroforestry is a potential option for transformation of, in parts, degraded lands into productive agricultural system. It also contributes to a rapid establishment of the fauna after land-clearing for agricultural use. Different agroforestry land use systems will affect the abundance and diversity of soil and litter fauna which in turn may restore the soil fertility and productivity. Agroforestry can contribute greatly to creating integrated agricultural and community systems that maintain productivity, protect natural resources, minimize environmental impacts, and provide for economic and social needs (Rietveld, 1996). Pastures have been found to enhance earthworm abundance but reduce the overall diversity, whereas agroforestry is known to conserve diversity and sustain high levels of abundance.

The North eastern region of India is having large diversity in farming system. Shifting agriculture, mixed cropping, horticultural orchards, tree farming system and different agroforestry systems (traditional) are practiced by the farmers of Mizoram. The presence of diverse earthworms and production of large quantity of cast in the agricultural field and forests during rainy season can be utilized for the better productivity by the farmers in the State. No comprehensive work has been carried out on the diversity and ecology of earthworms till date. Thus a need is felt to know about the distribution, diversity of earthworms of the State and their role in improvement of soil structure in different farming systems. Keeping the above facts in view, the present study is designed to achieve the following objectives:

(a) to study the earthworm species diversity, distribution and population in different farming system.

(b) to quantify the earthworm communities in terms of its abundance in different farming system.

(c) to study in depth the ecology of earthworm population in agroforestry system (experimental plots) considering the following aspects –

  (i) influence of the level of soil nutrients on the distribution and density of earthworm population.

  (ii) Total biomass and secondary production of earthworm population.

  (iii) Worm cast production and its nutrient status in relation to adjacent soil.

  (iv) Effect of fertilizers (N, P & K) on earthworm population dynamics and abundance.

Chapter 2

Review of Literature

2.1. Agroforestry system

The most precise definition of agro-forestry is “a land use system that involves deliberate retention, introduction or mixture of trees or other woody perennials in crop/animal production fields to benefit from the resultant ecological and economic interactions (Rao and Mac Dicken, 1991). Singh and Singh (2004) define agro-forestry as a sustainable land development system which combines the cultivation of trees along with crops.

Definitions and explanations given by Andriesse (1978), Torres (1983), Foley and Bernard (1984), Bentley (1985), Rocheleu and Raintree (1986), Labelle (1987), Rao (1989), Gordon and Bentley (1990), Lundgren and Raintree (1993), Balasubramaniyan and Palaniappan (2001), and Brady and Weil (2002) give pictures of different dimensions of agroforestry systems. Appropriate agroforestry system has the potential to control soil erosion, maintain soil organic matter and physical properties, augment nitrogen fixation and promote efficient nutrient cycling (Young, 1989). This system improves the productivity and maintains the fertility status of soil (Sinha, 1985; Jha, 1997).

Agroforestry system can also be defined as a land-use system that involves socially and ecologically acceptable integration of trees with agricultural crops and/or animals, simultaneously or sequentially, so as to get increased total productivity of plant and animal in a sustainable manner from a unit of farmland, especially under conditions of low levels of technological inputs and marginal lands (Anonymous, 1981).

Literature on agroforestry practice in north eastern India is scanty. Traditionally, the North-East region has been practicing a number of traditional agroforestry systems in different agro-climatic zones viz. Large cardamom based agri-silviculture and agri-herbiculture in Sikkim, Alder plantation in Nagaland, shade trees in tea and coffee plantations in Assam etc. However, majority of farmers of Mizoram are not yet practicing the agroforestry systems except for some on-farm demonstration (Lalnunmawia, 2007). Jha and Lalnunmawia (2003) stated that introduction of bamboo based agroforestry will help in reclamation of degraded shifting cultivation land in Mizoram. Jha (2000) introduced a new model of agroforestry as an alternative for jhum cultivation in the State.

2.2. Earthworm:

2.2.1. Morpho-ecological classification of earthworm:

Earthworm species can be classed in one of three morpho-ecological groupings, epigeic, endogeic, anecics (Bouché, 1977). Epigeic (Greek for “upon the earth”) species live in organic horizons and ingest large amounts of un-decomposed surface litter, serving as efficient agents of fragmentation of leaf litter. They tend to be small, pigmented with rapid generation times. These worms can be classified as phytophagous (Ismael, 1997). Endogeic (Greek for “within the earth”) species forage below the surface, ingest large quantities of soil with a preference towards organic rich soil, and build continuously ramifying burrows that are mostly horizontal. Ismael (1997) classified them as geophagous. Anecic (Greek for “up from” or “out of the earth”) species are known to build permanent burrows into the deep mineral layers of the soil, drag organic matter from the soil surface into their burrows for food (Card *et al.,* 2006), Ismael (1997) called these worms as geophytophagous. Werner (1990) recognized the anecic species as those worms that build permanent, vertical borrows that penetrate the soil deeply and they are detritivores.

2.2.2. Earthworm species diversity and distribution:

The distribution pattern and species composition of earthworms are found to be greatly controlled by the ambient climatic condition, physical and chemical properties of soil prevailing in a specific geographical area (Reynolds, 1995). Further, cultivation and types of agricultural practices also exert a significant influence on the abundance and intensity of these economically important worms (Ramanujam *et al*., 2000).

Of a worldwide total of almost 4,000 described earthworm species, detailed ecological studies have been made on fewer than 20 species, even which is mostly on the earthworms of temperate regions(Reynolds, 1998; Blakemore, 1999). The earthworm faunal distribution of subtropical and tropical regions is well documented from Australia, African Savannas and some tropical islands (Wood, 1974; Lee, 1985; Lavelle, 1983a; Blackmore, 1999). Temirov and Valiakhmedov (1988) reported the absence of earthworm in high-altitude desert soil of Tajikistan. Omodeo *et al.,* (1989) pointed out the presence of 51 earthworm species in Belgium. Sosa (1992) listed 20 species of earthworm from Canary Islands. Reynolds (1995) and Hendrix and Bohlen (2002) listed 147 earthworm species in North America. Blakemore (1999) reported 350 native earthworm species from Australia. Shih *et al.,* (1999) reported a total of 26 species of earthworms from Taiwan. Chu-fa Tsai *et al.,* (2000) reported the native and exotic species of earthworms in Taiwan with reference to Northeast Asia. Blakemore (2003) listed 77 earthworm taxa in seven families from Japan. Pavlícek *et al.,* (2004) reported 31 species of earthworm from Levant.

In peninsular India, with its diversified geographical zones, edaphic and climatic factors, their distribution has not received much attention except for early reports of Stephenson (1923). Gates (1972) in his work on Burmese earthworms has mentioned about earthworms of S.E. Asia and the Indo-Gangetic plains. Systematic studies on the earthworms of the Indian subcontinent were initiated in 1844 by Templeton (Julka, 1988). Though the area of India is only 2% of the world's total landmass, it harbours about 11% of the global earthworm diversity (Tripathi and Bhardwarj, 2004a).

Julka (1986, 1988) reported about 500 species of earthworms belonging to 27 families to be present in India. Julka and Senapati (1987) have listed 30 species of earthworm from Orissa. Ismail *et al.,* (1990) have reported the species richness and diversity in selected habitats in Madras city. Kale (1997) has described the earthworm faunal diversity in relation to three major geographical regions of Karnataka. Halder (1998) reported 63 species under 26 genera and 8 families from West Bengal. Chanda *et al.* (2003) have described 17 species of earthworms from Midnapore district of West Bengal. Tripathi and Bhardwaj (2004a) describe the diversity of earthworms in Jodhpur district of Rajasthan where 9 species of earthworms belonging to four families were identified.

Chaudhuri and Bhattacharjee (1999) have reported the presence of 17 species of earthworm belonging to five families from Tripura. Earthworms from Meghalaya were reported by Mishra and Ramakrishnan (1988) and Halder (1999). Ramanujam *et al*. (2000) has reported the presence of only five species of earthworm in Mizoram. The latest report on earthworm species composition of Mizoram indicates the presence of eleven species belonging to four families (Ramanujam *et al.,* 2004). Recently, Julka *et al.* (2005) reported the discovery of one new species viz., *Eutyphoeus mizoramensis* from Mizoram.

2.2.3. Seasonal variation in population dynamics:

Bhadauria and Ramakrishnan (1989) recorded a maximum number of earthworms in the rainy or late rainy period. This is supported by Bhadauria *et al.* (1997) and they observed a decline of all the earthworm species in the wheat crop mixture during November to April. Such perturbation related changes in population have been observed by Lofs Holmin (1983b). Mishra and Ramakrishnan (1988) observed two major peaks in population size, one in May - June and another in September - October. They have reported a decline in population size during the dry winter months of November to March. With raising soil moisture and decreasing temperature in the soil during rainy season, the proportion of juveniles increased rapidly, an indication that cocoons laid in winter and summer had started to hatch (Thambi and Dash, 1973). They mentioned that the population reached a maximum in late August - September and the proportion of immature and adults increased during the autumn - winter period indicating the growth of the individuals in the populations.

Sahu *et al.* (1988) reported zero population during summer revealing environmental drasticity (Soil temperature >31^{o} C, soil moisture <1g %) and yearly decolonization of worms. Earthworms are known to migrate to deeper layers (40 - 45 cm) during winter and summer (Reddy and Pasha, 1993). Rozen (1988), from his studies in Poland, has shown that densities of endogeic group of earthworms were highest in the spring and summer and lowest in winter. Kale and Krishnamoorthy (1982) reported that influence of climatic factors on earthworm community was species specific. They also assumed that trophic factors may influence the population numbers. Similar conclusion was made by Gonzalez *et al.* (1999). Gonzalez and Zou (1999) pointed out the influence of plant and litter on earthworm abundance may be negative or positive depending on the functional group of earthworms.

2.2.4. Influence of edaphic, climatic and farming systems on population of earthworms:

2.2.4.1. Soil and Topography:

Earthworms are called 'ecosystem engineers' (Jones *et al.,* 1994). According to El-Duwieni and Ghabbour (1965) an increase in organic carbon was associated with increase in worms. Similar observation was made by Kale and Krishnamoorthy (1981). The species richness was affected by various factors. Both physical and chemical properties of the soil significantly influence the earthworm population (Reddy and Pasha, 1993). Earthworm population is extremely variable in size, ranging from only a few individuals to more than 1000/m^2 (Edwards and Bohlen, 1996). Population sizes of earthworms were significantly correlated with soil moisture, temperature and organic matter (Bhadauria *et al.,* 2000). Liu *et al*. (2004) suggested that soil organic matter have significant influence on earthworm populations. Singh and Datta (1988) reported that a decrease in organic carbon and total nitrogen content with increasing depth of soil. Singh and Datta (1986) observed decrease in total potassium with increasing depth. Domínguez *et al*. (2004) observed that earthworm population was positively correlated with total N leaching flux (r^2=0.49*).* Suárez *et al.* (2003) found that earthworms significantly increased the amount of readily exchangeable P in the soil.

This finding suggests that Phosphorus level in soil has a positive effect on earthworm population density and distribution. Like-wise percentage of soil carbon has a positive correlation with earthworm abundance (Brown *et al.,* 2003). From their study on influence of earthworm community structure on the distribution and movement of solute in a chisel-tilled soil, Shuster *et al.* (2001, 2002) observed a higher concentration of soil organic matter, bromide and strontium in earthworm inoculated area compared to controls which suggest a positive relationship between soil organic carbon and earthworms. Similar observation was made by Scullion and Malik (2000), however, they stated that introduction of earthworm to a physically degraded land did not affect the total organic matter in the top 15 cm of soil. Organic matter removal decreased the average individual biomass of two species of earthworms (Jordan *et al.,* 2000).

Soil organic carbon, available nitrogen and potassium are important factors determining earthworm distribution and density (Reddy and Pasha, 1993).

The distribution of earthworms was mainly dependent on the physico-chemical characteristics of the soil (Tripathi and Bhardwaj, 2004a). Significant positive correlation with different soil nutrients and earthworms was observed (Tripathi and Bhardwaj, 2004b). Reddy and Pasha (1993) observed that the seasonal population structure was significantly influenced by the seasonal patterns in rainfall, soil temperature, pH, electrical conductivity and phosphorus. They also concluded that the physical factors of the soil were collectively more effective in causing the seasonal variation in the population size of earthworm than the chemical factors. Decaëns *et al.* (2004) are of the opined that earthworm community composition and diversity were mainly determined by soil type. Krishnamoorthy (1989) reported that earthworms are not found in heavy sands and acid soils. He also stated that sandy loams had a greater species diversity as well as population diversity than the clays.

In nature, earthworms distributes horizontally or vertically. Horizontal distribution depends upon many factors like temperature, moisture, mineral contents, aeration, availability of the reproductive potential and their overall adaptability. Vertical distribution varies seasonally due to habitat preferences and feeding habits *etc*. (Bhatnagar and Palta, 1996).

Soil pH is often cited as a limiting factor on earthworm distribution (James, 2000). Earthworms are generally absent from very acid soils ($pH < 3.5$) and are scarce in soils with pH < 4.5 (Curry, 1998). While there are considerable differences between species in their preferred pH, the majority of temperate climate species are found in the range 5.0 – 7.4 (Satchell, 1967). On the other hand, Michalis *et al.* (1989), from their studies on earthworms as Central west Macedonia (Greece), reported that an optimum soil pH for earthworms ranges from 4.9 – 6.9, and the number of individuals decreased significantly with increasing pH. Mele and Carter (1999) pointed out that lowering the pH consistently lowered earthworm densities (by 60%). Increased sand content of the soil was significantly related to increased number of species.

Earthworms prefer materials with a low C/N ratio, such as clovers, to grasses which have a higher C/N ratio (Ruz Jerez *et al.,* 1988). In contrast to this, Kale and Krishnamoorthy (1981) observed a decline in earthworm density with lower C/N ratio. Singh and Datta (1988) and Kaushal *et al.* (1995) stated that the C/N ratio of the soil decreased with increasing depth of the soil.

El-Duweini and Ghabbour (1965) reported that Earthworm population densities are affected by soil textures. Similar observation was made by Cotton and Curry (1980). Decreasing population densities of *A. caliginosa* were linked with increasing proportions of sand and gravel in Egyptian soils (El-Duweini and Ghabbour, 1965), while low earthworm densities (max. 73 m^{-2}) occurred in sandy and silty coastal grassland sites in Co. Wexford, Ireland, compared with similarly managed loam soils (max. 516 m^{-2}) (Cotton and Curry, 1980). There are reports on population densities of earthworms in different parts of the world (Barley, 1959; Satchell, 1967; Reynolds, 1969, 1970, 1971, 1972). Dash and Patra

(1977) are of the opinion that the differences between the population densities in different world sites can be attributed to earthworm species, soil types, vegetation, climate and altitude. Kale (1997) stated the distribution pattern of the earthworms and their population density in Karnataka is closely associated with moisture content, soil characteristics, vegetation and the land use practices. Gerrard (1986) reported that earthworm distribution is more related to altitude than to human activities. Kale and Krishnamoorthy (1978) reported that earthworm population density of the species is not at all related to the organic matter of the soil.

Chu-fai Tsai *et al.* (2004) reported that elevation defines the distributional ranges of earthworms, with the decrease in elevation, number of native species decreased while number of exotic species increased in Taiwan.

2.2.4.2. Climate:

Temperature may be a factor of primary importance in determining the composition and structure of earthworm communities (Lavelle, 1983b; Lavelle *et al*., 1989). As soil temperatures rise and the soil moisture levels decrease, endogeic earthworms burrow deeper into the soil profile, and enter into a state of quiescence during which they curl themselves into a tight ball to reduce water loss, and reduce their metabolic rates until conditions become favourable (Edwards and Bohlen, 1996).

High temperatures are often associated with moisture shortages, this results in seasonal earthworm mortality (Gerard, 1967; Phillipson *et al.,* 1976).

Soil temperature influences seasonal activity, limiting earthworms during warm and cold periods (James, 2000). Baker (1998) and Aroujo and Hernandez (1999) has demonstrated the importance of soil moisture content in determining earthworm distribution and activity. Like-wise, James (2000) stated that soil moisture affects earthworm abundance, activity patterns and geographic distribution. Evans and Guild (1947) found that soil moisture is an important regulating factor for earthworm populations. In general, earthworms are most active at moisture tensions approaching field capacity (~10 kPa), while activity declines rapidly as the moisture tension exceeds 100 kPa and ceases for most species below permanent wilting point (1500 kPa) (Lavelle, 1974; Nordström and Rundgren, 1974; Nordström, 1975; Baker *et al.,* 1993). Eriksen-Hamel and Whalen (2006) have opined that the instantaneous growth rate (IGR) was affected significantly by soil moisture and temperature. Whalen *et al*., (1998) observed the influence of soil temperature and moisture on fluctuations in numbers and biomass of earthworm. Similar observation was made by Bennour and Nair (1996). Rainfall, soil temperature, pH and electrical conductivity influenced the seasonal population structure (Reddy and Pasha, 1993).

2.2.4.3. Cropping systems and management:

Major determinants of earthworm community structure in an agroecosystem are the quantity and quality of organic matter added to the soil type and the influences of the disturbances (Werner and Dindal, 1989; Lavelle *et al.,* 1994; Fraser, 1994). The changes in land use pattern are directly affecting the composition and population structure of earthworm species in different agro-climatic regions (Blanchart and Julka, 1997; Behera *et al.,* 1999; Bhadauria *et* *al.,* 2000). Sinha *et al.* (2003) suggested that distribution of earthworm functional groups is determined by land use practices. Bhadauria and Ramakrishnan (1989) reported that earthworm population declined significantly after slash and burn. Critchley *et al.* (1979) and Lavelle and Pashanasi (1989) also observed that slashing, burning and cropping reduce earthworm density, diversity and activity. But, in another slash and burn situation, Darlong and Alfred (1991) did not find any loss or replacement of earthworms by another species.

Soil type mainly determines earthworm community composition at the scale of soil type patches, while agricultural practices have a stronger impact on community structure at the scale of the agricultural plot (Decaëns *et al.,* 2004). The changes in soil properties as a result of deforestation directly altered the earthworm communities (Dotson and Kalisz, 1989; Bhadauria *et al.,* 1997; Blanchart and Julka, 1997). The change in the natural population structure of earthworm species due to disturbance and degradation of natural forest has been reported by Satchel (1983) for temperate regions and by Fragoso and Fernandez (1994) for tropical regions.

Studies conducted in different parts of the world have shown that earthworm populations increase with reduced soil disturbance (Clapperton *et al.,* 1997; Clapperton, 1999; Brown *et al.,* 2003). Rossi and Blanchart (2005) showed that land management induced significant changes in the soil macrofauna. Similar conclusion was made by Beare *et al.* (1997), Fragoso *et al.* (1997), Giller *et al.* (1997), Curry (1998), Barros *et al.* (2002, 2003) and Decaëns *et al.* (2004).

Earthworm populations are affected by agricultural management (Binet *et al.,* 1997; Paoletti *et al.,* 1998; Chan, 2001). According to Paoletti (1999) and Curry *et al.,* (2002), earthworm populations in cultivated land are generally lower than those found in undisturbed habitats. Agricultural activities such as plowing, several tillage operations, fertilizing and application of chemical pesticides have dramatic effect on invertebrate animals. Any management practices applied to soils are likely to have some (positive or negative) effects on earthworm abundance and diversity; these effects are primarily the result of changes in soil temperature, soil moisture and organic matter quantity or quality (Hendrix and Edwards, 2004). A variety of agricultural land use practices, such as reduced or no tillage, the addition of organic amendments, and certain crop rotations are reported to increase earthworm population (Lee, 1985; Edwards and Bohlen, 1996; Chan, 2001; Donahue, 2001). There are reports that cultivation tends to have a negative effect on earthworms by decreasing moisture (Springett *et al.,* 1992; Fraser, 1994). Low (1976) has reported noticeable decline in earthworm population in arable lands in England over the old grassland population. He reported a population of 50 - 180 worms/m^2 in old grasslands and a mere 1 - 20 worms/m^2 in cultivated lands. Zisci (1958) reports similar observations in Hungary. Annual crops are reported to be relatively unfavourable systems for soil macrofauna, and in general have low earthworm biomass (Lee, 1985). A negative influence of cropping on the population of earthworm in New South Wales was reported by Friend and Chan (1995). Wyn and Glanteller (1992); Smeaton *et al.,* (2003) emphasized the negative effect of ploughing on earthworm population. Mele and Carter (1999) reported a reduced earthworm density (by 53 %) in a stubble burnt situation compared to mulched system.

Differences in tillage, nutrient inputs, and crop rotation can influence the size and species composition of earthworm populations (Edwards and Bohlen, 1996). Earthworms are not favoured by tillage, and in general the greater the intensity and frequency of disturbance, the lower the population density or biomass of earthworms (Barnes and Ellis, 1979; Gerard and Hay, 1979; Edwards, 1983; Mackay and Kladivko, 1985; Haukka, 1988; Reddy *et al.,* 1997; Hutcheon *et al.,* 2001; Brown *et al.,* 2003; Birkas *et al.,* 2004). Shuster *et al.,* (2003) are of the same opinion, they also pointed out that deep burrowing earthworm species are particularly affected by tillage.

Edwards and Bohlen (1996) observed 70 per cent reduced in earthworm population after five years of ploughing. Wyn and Glanteller (1992) observed that tillage reduced earthworm abundance by 50 per cent and biomass by 30 per cent. Coleman and Crossley (1996) in Georgia observed earthworm density of $967/m^2$ in no till fields compared to $149/m^2$ in conventionally tilled fields. In Nigeria, Edwards and Lofty (1977) reports the presence of 2400 earthworm casts/m^2 in no till plots compared to 100 casts/m^2 under conventional tillage. Edwards *et al.* (1995) reported up to 30 times more earthworms in no-till systems compared to plowed fields. They also mentioned that irrigation and drainage have positive effect on earthworms.

Further, there have been numerous reports indicating higher earthworm population under conservation tillage compared with conventional tillage systems (Barnes and Ellis, 1979; Gerard and Hay, 1979; Edwards and Lofty, 1982c; Lal, 1982; House, 1985; Rovira *et al.,* 1987; Bohlen *et al.,* 1995; Jordan *et al.,* 1997).

Total earthworm populations under no-tillage have been found to be 2 - 9 times greater than that found under conventional tillage (Chan, 2001). Lee (1985) and Chan (2001) are of the opinion that the higher earthworm populations under conservation tillage systems have often been attributed to the more favourable soil conditions, namely presence of surface litter, more favourable temperature and moisture conditions, and the lack of disturbance.

However, Boone *et al.* (1976) and Kladivko *et al.* (1997) have reported a negative response of earthworm abundance to no-tillage. Reddy and Reddy (1990) reported that earthworm's populations recover after a second tillage although density fluctuation was observed during their study periods in grassland. In general, the greater the intensity and frequency of disturbance, the lower the population density or biomass of earthworms (Mckay and Kladivko, 1985).

Toxic pesticides and its residue are known to decrease earthworm populations (Lofs-Holmin, 1983a; Berry and Karlan, 1993; Hendrix, 1998; Edwards and Bohlen, 1996; Ernst, 1995; Donahue, 2001). Spurgeon and Hopkin (1999) found that earthworm density was highly reduced near the smelting work factory in Avonmouth, UK. No earthworms were found in soils contaminated with metal emissions from a primary smelting works (<0.6 km).

Grazing management was found to be strongly correlated with earthworm abundance in Swiss grassland (Muldowney *et al*., 2003). Andersen (1987) reported that direct drilling have positive effect on earthworm population, he stated that earthworm density was increased and biomass also increased by three folds. This observation was supported by Francis *et al.* (1987).

Whalen *et al*. (1998) have shown that under continuous corn cropping, the earthworm populations in both manure and inorganic fertilizer plots have declined significantly. Rovira *et al*. (1987) reported that crop rotation does not affect earthworm density.

Bhadauria *et al.* (1997) found that under similar conditions of land management activities and cultivation and with similar type of cropping patterns, *Drawida* sp. was dominant and certain species like *metaphire houlleti* are able to withstand disturbances caused by intensive agricultural practices. They have also reported the adverse effect on earthworm population and species composition of various land management practices, such as ploughing, harrowing and cult-packing of the soil in agricultural system during crop rotation. Earthworm abundance, density and distribution were determined by type of vegetation (Gonzalez *et al.,* 1999; Ramanujam *et al*., 2004).

Didden (2001) reported that abundance, biomass and species richness were significantly higher in grassland soils than in horticultural soils. He found no epigeic species in horticultural soils. Zou and Gonzalez (1997) found that successional development from grass-dominated pastures to woody species-dominated forests reduces earthworm density and diversifies worm community structure in humid tropical soils. Ortiz and Fragoso (2004) also found the type of available food material affects the population abundance.

Soil compaction caused by agricultural traffic can also decrease earthworm populations (Boström, 1986). Those that live within the surface layers generally migrate to lower depths during the summer as the soil becomes drier. Reddy (1983) observed that earthworms were found in the upper (0 – 10 cm) layer of the soil during rainy season but penetrated downwards into the deeper soil as winter approached. Cultivation may enable earthworms to penetrate further into the soil. Repeated row cropping will reduce the number of earthworms, while the inclusion of grass or field crops in a rotation and intercropping will encounter this effect (Ramsay and Hill, 1978). Kale (1997) reported decline in the earthworm population in cultivated land compared to grassland.

Earthworms are not distributed randomly in soil. The number of earthworms in regular arable soil is usually very low, due to mechanical damage during cultivation, to a loss of the insulating layer of vegetation, to a decreased supply of food as organic matter which gradually decreases with repeated cultivation or to predation by birds. Earthworms may be absent or rare in soils with coarse texture probably due to the susceptibility to drought of such soils (Lee, 1985).

Barros *et al*. (2002) observed a high earthworm density in pastures compared to fallow, annual cropping and agroforestry systems. They pointed out that in most cases; annual cropping systems greatly decrease the diversity and abundance of soil fauna communities, while Lavelle *et al.* (1994) suggest that annual crops always have highly depleted macroinvertebate communities. Lavelle and Pashanasi (1989) observed that in Peruvian Amazona significant change in the biomass and diversity of the soil macrofauna occurred after establishment of pastures an annual crops.

Norgrove *et al*. (2003) suggests a positive influence of mulching on earthworms. Irrigation and drainage are also reported to have positive influence on earthworms (Donahue, 2001). Christensen *et al*. (1987) found a positive influence of cultivation practices on earthworm population. They suggest that effects of cultivation on earthworm population responds to the type of cultivation, in particular crop, fertilizer and soil tillage. Samuel (1988) found that biomass of earthworms increased with burning and positive correlation with irrigation.

2.2.5. Biomass and Secondary Production:

Springett *at al.* (1998) in their experiment from New Zealand observed that the biomass of earthworm was significantly correlated with soil organic matter but was negatively correlated with spring pasture productivity. Gonzalez *et al.* (1999) reported that the density and biomass of earthworm in plant community were not correlated with soil pH, soil water content or forest floor litter. Baker (1983) found that total densities and biomasses of the earthworms were greater where the soil was drier. Whalen and Parmelee (2000) stated that earthworm biomass and secondary production were greater in manure treatment than inorganic fertilizer treatment.

Satchell (1967) reported that estimation of earthworm biomass based on formaldehyde sampling and hand sorting are 100 - 287 g wet weight/m^2 for many European sites. Reynolds (1973) observed biomass of earthworm as 3 - 169 g wet weight/m^2 for many grassland sites of Tennessee, U.S.A. The biomass estimate of megascolecidae for tropical grassland at Behrampur, Orissa, India ranged from 6 - 60 g wet weight/m^2 with an average monthly biomass of 30.25 g/m^2 (about 8 g dry weight) (Dash *et al.,* 1974). Dash and Patra (1977) determined a net production of about 140 g wet weight/m^2 (about 35 g dry weights).

Mishra and Ramakrishnan (1988) observed fluctuations in earthworm biomass similar to density, with two peaks one in May and July and another on October - November. The seasonal dynamics over an annual cycle have shown that the earthworm populations and biomass were high in the rainy and early winter season and low in summer (Bhadauria and Ramakrishnan, 1989; Kaushal and Bisht, 1994). Senapati and Dash (1983) reported an average monthly live earthworm biomass in the lowland was 32 g (8g dry wt)/m^2 and 56 g (11 g dry wt)/m^2 in the upland pasture sites of Orissa, India. Reddy and Reddy (1990) concluded with the recovery of earthworm biomass after a second tillage in grassland. Thambi and Dash (1973) reported that the average monthly biomass of enchytraeidae (oligochaeta) is 10.8 g/m^2. Vandecasteele *et al.* (2004) observed highest earthworm biomass on sandy loam dredged sediment-derived soils (DSDS) disposed at least 40 years ago compared to surrounding alluvial plains. Lee (1985) found that the earthworms in term of biomass constitute the principal component of the total faunal biomass in temperate regions.

Data on secondary production of earthworms are not available for many parts of the globe. Lakhani and Satchell (1970), and Satchell (1970) showed 100 g wet weight/m^2 of secondary production for *Lumbricus terrestris.* Lamotte *et al.* (1974) give secondary production of a species of earthworm, *Millsonia anomata* in the Ivory Coast as 46 g/m^2/year with a population biomass turnover of 7 times the average biomass.

Thambi and Dash (1973) observed the energy input in their experimental site in Behrampur, Orissa amount to 7680 Kcal/m^2/year. Dash and Patra (1977) observed the secondary production of earthworms of Behrampur, Orissa as 140 g wet weight/m^2/year (35 g dry weight/m^2). Similar result was obtained by Dash *et al.* (1974). They also observed that the population biomass turnover (ratio of secondary production to the average biomass) was around 4.5 for Oligochaetes of Behrampur. Senapati and Dash (1983) reported that the secondary production of earthworm amounts to 678 kJ/m^2/year in the low land and 511 kJ/m^2/year in the upland pasture site of Orissa.

Estimates of earthworm community secondary production can quantify the direct role of earthworms in the C and N cycle (Parmelee and Crossley, 1988). Parmelee *et al.* (1998) stated that secondary production estimates the C and N flux through earthworm tissue as the sum of the production of new earthworm tissue and the loss through mortality.

2.2.6. Earthworm influences:

Earthworms are known to increase soil bulk density, soil porosity, mixing of organic matter, and to strengthen aggregation of soil particles (Price and Gordon, 1999; Shipitalo and Le Banayon, 2004). They produce structural features at three different scales of soil porosity (Lamandè *et al.,* 2003). In relation to macropore space (>1 mm), earthworm burrow networks act as preferential flow paths (Schrader *et al*., 1995; Bouchè and Al-Addan, 1997; Trojan and Linden, 1998). At a smaller scale, earthworms may change the pore space between mineral and organic particles, i.e. the microporosity, and the stability of soil structure (Shipitalo and Protz, 1989; Blanchart *et al.,* 1993; Chauvel *et al.,* 1999). Earthworms affect the pore structure of soil through burrowing and casting (Lavelle, 1997). Earthworm casts also exhibit greater moisture retention capacity (Ziegler and Zech, 1992; Zhang and Schrader, 1993; Devliegher and Verstraete, 1997) than bulk soil. Pérès *et al.* (2005) concludes that, earthworms, by creating specific burrow network, influence the infiltration of water in soil. Robert *et al.* (2004) suggest that earthworms preferred loose soil than compact soil.

2.2.7. Worm cast production and its nutrient status in relation to adjacent soil :

Madge (1969) stated that 13.3 % moisture level was found to be optimum to produce casts. It was found that slashing the vegetation caused a severe decline in surface casting activity, whether or not the plot was cropped afterwards. There is no correlation between surface cast production and soil water content or soil temperature (Norgrove *et al.,* 2003). However, other researchers found that seasonal variations in cast production were attributed to fluctuations in soil moisture and temperature, and in food supply (Sharpley and Syers, 1979). Norgrove and Hauser (2000) showed that cast production was affected by the pattern of land use.

Singh and Dev (1987) reported a maximum amount of casting produced by the worms in the month of June. Whalen *et al.* (2004) reported that cast production is influenced by temperature; they observed a higher cast production as soil temperature increased. Springett and Syers (1984) reported that cast production increased with increasing soil pH and Ca level but did not increase with increasing Ca when soil pH was constant. Earthworm excretion of nitrogenous compounds in urine and mucus may provide a particularly labile N source for soil microbes. Earthworm urine is composed primarily of ammonium and urea (Parmelee *et al.,* 1998). Mucus is composed of mucoproteins with low C/N ratio of 3.8 (Scheu, 1991). The amounts of N excreted in urine and mucus could be substantial (Lee, 1983; Dash and Patra, 1979).

Bano *et al.* (1987) observed the superior quality of worm cast compared to other organic manures. They stated that worm cast is rich in humus forming microbes and nitrogen fixers and that the drying of the cast has not deteriorated the microbial population. Therefore, these characteristics qualified the worm cast as bio-fertilizer. Nitrogen fixing bacteria are found in the gut of earthworms and in earthworm casts, and higher nitrogenase activity, meaning greater rates of N-fixation, are found in casts when compared with soil (Simek and Pizl, 1989). Sculion *et al.* (2002) found that casts from conventional and organic arable rotation systems had markedly higher organic contents, stability, available P and K concentrations, and microbial biomass than underlying soil. However, Agarwal *et al.* (1958) reported an adverse effect of worm cast on soil structure.

Earthworm casts typically have higher microbial biomass and respiration rate than bulk soil (Scheu, 1987; Lavelle *et al.,* 1992; Mishra and Dkhar, 1992). Tomati *et al.* (1987) reported that earthworm cast have a hormone like effect on plant growth, but this effect is linked to microbial metabolites in the casts.

Soil microorganisms live in the worm's gut as well as the surrounding soil and so the microbial content of casts is usually more concentrated than in surrounding soil. Microbial activity in worm castings is 10 to 20 times higher than in the soil and organic matter that the worm ingests (Edwards, 1994). Similar conclusion was obtained by Dkhar and Mishra (1986). Level of microbial activity differs from species to species (Haynes *et al.,* 2003). Microbial activity in casts improves soil structure by encouraging aggregation of particles. Microbial secretions (gums) and growth of fungal hyphae stabilize the worm cast. Worm-worked soil is relatively water-stable and will resist soil compaction and run-off due to rains (Edwards and Lofty, 1977).

Bhadauria and Ramakrishnan (1989) found that worm casts had higher pH and better nutrient status than soil. They concluded that worm casts are local concentrations of nutrients. Edwards (1988) reported that worm-worked composts have better texture and soil-enhancing properties; hold typically higher percentages of nitrogen, potassium, and phosphorous; and may offer plants disease-fighting properties. Earthworm excreta (castings) are an excellent soil-conditioning material with a high water holding capacity and a natural time release for releasing nitrogen into the soil (Harris, 1990). Domìnguez *et al.* (1997) stated that Vermicompost (castings) is a finely divided peat like material with excellent structure, porosity, aeration, drainage and moisture-holding capacity. Similar clue was obtained by Edwards and Burrows (1988). Edwards (1998), Hidalgo and Harkess (2002).

Birang *et al.* (2004) observed that cast production was not correlated with soil chemical properties across and earthworm species assemblages is likely to be the main factor determining surface cast deposition in their studies in humid forest zone of Southern Cameroon. They also stated that more casts were deposited in undisturbed land than in regular cropped land. Thus, cropping reduced cast production.

Bhattacharya and Chakraborti (1987) found a higher pH in the cast of *Perionyx excavatus* and *Lampito mauritii* than in the adjacent soil. Similar observation was made by Nye (1955) and Vurma and Chauhan (1979). In contrast to these observations Nijhawan and Kanwar (1952) noted a lower pH value for the worm cast soils of Punjab.

Organic carbon content was also higher in worm cast compared to adjacent soils (Madge, 1969; Gupta and Sakal, 1987). This observation was followed by Zhang and Schrader (1993) who found that the organic C content is increased by 21.2 – 43.0 % for cast. But Bhattacharya and Chakraborti (1987) observed lower organic carbon from their studies in the cast of Tripura. They also found lower total nitrogen in worm cast than in adjacent soil. Bossuyt *et al.* (2005) reported that soil organic carbon was protected within worm cast by micro-aggregates within large macro-aggregates leading to a possible long-term stabilization of soil carbon.

Krishnamoorthy (1984) reported decreased C/N ratio from soil to cast. Similar observation was reported by Julka and Mukherjee (1984), Nijhawan and Kanwar (1952) while Kale and Krishnamoorthy (1977) opined that the earthworms increase C/N ratio of soil. Bhattacharya and Chakraborti (1987) reported that *Perionyx excavatus* showed a decreased C/N ration from soil to cast but increased from soil to cast in *Eutyphoeus* sp. and *Lampito mauritii.*

Syers *et al.* (1979) reported that Lumbricids in a pasture soil produced casts that contained 73 percent of the nitrogen found in the ingested litter; indicating both the importance of earthworms in incorporating litter nitrogen into the soil and the inefficiency of nitrogen digestion by earthworms. Earthworm activity increased soil mineral-N concentrations (Aroujo *et al.,* 2004). Earthworms increase the amount of nitrogen mineralized from organic matter in soil; because nitrification is enhanced in earthworm casts, the ratio of nitrate-N to ammonium-N tends to increase when earthworms are present (Ruz Jerez *et al.,* 1988).

Dash and Patra (1979) and Patra (1975) reported that worm casts contained some 0.47 per cent of nitrogen compared with 0.35 % of nitrogen in the surrounding soil. They estimated that about 9.29 g of nitrogen/m^2/yr returned to soil through worm casts. According to this, some 180 kg/ha/year of nitrogen was returned to soil through mucus secretion, worm cast production and dead tissue of earthworm. Satchell (1967) reported some 100 kg/ha/year of nitrogen returned to soil from European sites.

Parkin and Berry (1994) also concluded that earthworm castings were enriched in mineral N, compared with the surrounding soil. Other researchers found that earthworm castings generally have a higher ammonium concentration and water-holding capacity than bulk soil samples, and they constitute sites of high denitrification potential (Elliot *et al.,* 1990). The concentration of $NH4^+$ in the castings of earthworms can increase during gut passage of the ingested soil and after the soil material has been egested as castings. Bohlen and Edwards (1995) stated that earthworms had significant effects on the amount of extractable NO_3^-, which increased with time. Kelkar (1949) reported a higher nitrifying power of the casts than the surrounding soil.

Satchell and Martin (1984) and Satchell *et al.* (1984) found that alkaline phosphatases are excreted in worm casts. The worm casts are not only richer in soluble inorganic phosphates but also in exchangeable phosphorus (Sharpley and Syers, 1976; Mansell *et al.,* 1981). Similar observation was made by Krishnamoorthy (1990) where he suggested that the higher phosphatase activity of worm cast than that of the undigested soil, which increases the inorganic phosphorus released by mineralization. He stated that among the four species of earthworm he studied, *Perionyx excavatus* showed a highest faecal phosphates activity. While a higher phosphates activity in undigested soil has been demonstrated in the worm casts of some temperate worms (Satchell and Martin, 1984; Satchell *et al.,* 1984).

The enrichment of earthworm casts in essential plant nutrients such as N, P, K, Ca and Mg has been demonstrated by several workers (Lunt and Jacobson, 1944; Parle, 1963; Graff, 1970). Following this report, Krishnamoorthy (1990) observed that worm casts have all major components that are essential (NPK) to regard them as field fertilizers.

Lunt and Jacobson (1944) reported that the casts from a ploughed field had approximately three times concentration of exchangeable Mg, seven times of available P and eleven times of available K than the top 150 mm of soil. Sharpley and Syers (1976) noted that the surface casts contain approximately four times more loosely bound inorganic P and two times as much as loosely bound organic P as underlying soil.

Several studies have also indicated that the amount of available P in earthworm casts is greater than the underlying soil (Barley, 1961; Gupta and Sakal, 1967; Graff, 1970; Vimmerstedt and Finney, 1973). Kuczak *et al.* (2006) revealed the higher levels of organic hydroxide P in earthworm casts than surrounding soil.

Basker *et al.* (1993) point out that studies carried out under field conditions indicated that the castings of earthworms contained two to three times more available K than the surrounding soil. Nutrient concentration of earthworm cast dependent on the food source available (Shipitalo *et al.,* 1988). Norgrove *et al.* (2003) pointed out that earthworm casts derived from mulched plots had higher N and K concentrations than those from non-mulched plots. Farenhorst and Bowman (2000) observed no significant differences in casting production rates among earthworms fed different foods.

Vleechauwer and Lal (1981) found the presence of less sand, more silt and clay in the casts compared to surface soil. They also found that casts had greater bulk density and structural stability than the surface soil. The higher amount of N, organic matter content, available P and cation exchange capacity were also estimated from the worm's casts. Krishnamoorthy and Vajranabhaiah (1986) noted higher values of ammonia, urea, organic carbon content, organic matter, soluble phosphorus and ionic potassium levels in the casts.

2.2.8. Effect of fertilizer(NPK) on earthworm population:

Bugg (1994) observed that fertilizer have specific effects on earthworms depending on the type of earthworm and fertilizer used. He reported that ammonium sulfate and sulfurcoated urea reduced population of *Apporectodea caliginosa* and *A. rosea*. He also noted that while nitrochalk had a little effect on earthworm densities, other fertilizers had intermediate effects. Muldowney *et al.* (2003) suggests that fertilizer use was strongly correlated with earthworm abundance in Swiss grassland.

Timmerman *et al.* (2006) observed a lower (≥ 29 %) earthworm abundance and a higher mean individual body weight in slurry manure treatment than the farmyard manure and no fertilization treatment from their studies on the effects of fertilization regime on earthworm abundance in a semi-natural grassland area of The Netherlands. Earthworm numbers and biomass were significantly greater in manure-amended plots compared to inorganic fertilizer-treated plots (Whalen *et al*., 1998, Whalen and Parmalee, 2000). Organic fertilization increased several soil fertility parameters (N, P, K, Ca, and Mg), this improved fertility status has probably allowed the establishment and dominance of earthworm; enhanced earthworm abundance could increase enzymatic activities as well as microbial biomass (Lopez-Hernandez *et al.,* 2004). Watkin and Wheeler (1966) observed a positive influence of nitrogen fertilizer on earthworm population under pastures of England and New Zealand.

There are reports on harmful effects of inorganic fertilizers on earthworm population (Edwards and Lofty, 1975; Zajonic, 1975; Gerard and Hay, 1979; Brussard and De Ridder, 1990). Edwards and Lofty (1974) reported that application of inorganic fertilizers decreases earthworm populations. Edwards (1983) stated that heavy application of inorganic fertilizers may cause immediate reductions in earthworm abundance. Sahu *et al*. (1995) reported on the effect of fertilizers on earthworm structure and dynamics in cane sugar field from India, indicating about 30 per cent decrease in worm population and decrease in the reproductive rate of earthworm.

Heavy applications of some nitrogenous fertilizers, especially those which have a strong soil acidic effect, can depress earthworm populations (Nowak, 1976; Ma *et al.,* 1990). Anhydrous ammonia and ammonium sulfate have been found to have negative effects on earthworms. This may be due to the acidifying effect of this fertilizer, and also due to the toxic effect of ammonia. Ammonia and ammonia-based fertilizers can adversely affect earthworms (Donahue, 2001). Annual use of ammonium sulfate, anhydrous ammonia and sulfur coated urea has been shown to decrease earthworm population (Edwards *et al.,* 1995).

Scullion and Ramshaw (1987) found that NPK fertilizer discouraged earthworm casting and burrowing to the surface, the reduction in casting becoming larger at higher rates of NPK application. Potter *et al.* (1985) showed a severe reduction in earthworm population after application of N fertilizer at Kentucky blue grass. Marhan and Scheu (2005) observed that NPK fertilization is insufficient to sustain *Octolasion tyrtaeum* (Savigny), whereas long term fertilization with farmyard manure enables survival of endogeic species due to an increased pool of utilizable soil organic matter in arable soil of Germany.

Some authors claim that inorganic fertilizers are beneficial to earthworms (Zajonic, 1970; Gerard and Hay, 1979; Edwards and Lofty, 1982a; Reddy and Ground, 1987; Tiwari, 1993; Callaham *et al.,* 2003). Inorganic nitrogen fertilizers promote greater plant production than in unfertilized fields and therefore higher earthworm populations (Steffey, 2003). Edwards and Bohlen (1996), Kale (1997) and Edwards *et al.* (1995) were of the opinion that inorganic fertilizers have indirect positive impact on earthworm numbers.

Earthworms may have a significant role in maintaining or enhancing plant growth and reducing use of fertilizers (Lee, 1985). Sjoerd (2003) reported that most inorganic fertilizers favour the build up of large numbers of earthworms, probably due to the increased amounts of crop residues being returned to the soil. Tiwari (1993) observed that applications of fertilizer caused significant increases in earthworm numbers, biomass, and casts. N alone or in combination with P and K also influenced these earthworm parameters significantly. He pointed out that the inorganic NPK fertilizer in combination with organic manure had a significantly greater effect on earthworm activities than NPK fertilizer alone. Nearly all organic fertilizers benefit earthworms (Donahue, 2001).

Liming to neutralize acidify stimulates earthworm activity. Lime may indirectly benefit earthworms by increasing plant growth and therefore plant residues (Donahue, 2001). Edwards *et al.* (1995) reported that their study in New Zealand showed a 50 % increase in surface feeding earthworm species by adding one ton of lime per acre. Hendrix *et al.* (1992) reported that earthworm numbers in meadows receiving inorganic fertilizer averaged nearly twice the earthworms in unfertilized meadows on the Georgia piedmont. Beneficial effects of mineral fertilizers have been attributed to improved litter quality and quantity, while organic manures represent valuable additional sources of food for earthworms (Curry 1976; Edwards and Lofty 1982b; Lofs-Holmin, 1983b).

Mishra and Tripathy (1988) concluded that earthworm population density, average length and biomass were enhanced by nitrogen fertilizer application from their study at grassland site of Orissa, India. They also reported that the above ground net primary productivity was increased by 50 % due nitrogen fertilizer application and earthworm secondary productivity increased from 8.8 to

13.9 g dry tissue m^{-2}. Reddy and Ground (1987) found that the application of organic manure, inorganic fertilizer(DAP) and Urea fertilizers increased the population density of an earthworm species, *Malabaria sp.* inhabiting rice nursery beds by 29.5, 18 and >113 % respectively after 30 days of treatment.

Chapter 3

Study area, Experimental Design and Methodology

Study area:

Location

Mizoram, having an area of 21,081 sq. km., lies between 21°56’ N and 24°31’N latitude and 92°16’ E and 93°26’E longitude (Pachuau, 1994). The state has international borders of Bangladesh in the west and Myanmar in the east and south. On the northern side it borders with three states of India viz. Tripura in North West, Assam in north and Manipur in north east. Being sandwiched between Bangladesh and Myanmar, its location is geographically and politically significant (Fig. 1). The hilly state is covered with tropical and subtropical forest cover. It is one of the hot spots of biodiversity. The gorges are steep with north-south trending mountains. The average temperature varies between 11^{o}C and 21^{o}C in winter and climbs up to 20^{o}C and 32^{o}C in summer months. The monsoon season stretches from mid May to mid October. The annual rainfall is about 250 mm.

Soil Structure

All the soil profiles show distinct horizonation with clear differentiation. The texture of surface soil varies from loam to clay loam at higher altitudes and from clay loam to silty clay loam at lower altitudes. Subsurface soils are more sticky and plastic than the surface soils. The most common feature of the soil is the predominant presence of fine and very fine sand sized particles in the profile. Sand is the dominant fraction in the surface horizon and it decreases with depth. The soil is acidic in reaction, and the soil acidity increases with altitude (Singh, 1983).

Study Sites

Study sites are grouped in two parts. Group A: No. 1 to 11 experimental plots were laid at different locations in Mizoram (Fig. 2) having different crop combinations and plantations to study earthworm species diversity, distribution, population to achieve objectives number (a) and (b) and Group B: No.1 and 2 agroforestry based experimental plots were laid down taking into account experimental design and treatments to achieve the objective number (c) (i) to (iv) (Fig. 2). Details about the crops combination in mixed cropping and plantations are presented in Table.1.

Group – A:

1. Teak plantation, near Tuirial river (15 km, east of Aizawl) located at $92^o47'$E and $23^o44'$N.
2. Orange plantation, S. Hlimen (5 km south of Aizawl) located at $92^o43'$E and $23^o41'$N.
3. Banana plantation (5 km south-west of Aizawl) located at $92^o42'$E and $23^o43'$N.
4. Tlangnuam mixed plantation, Aizawl located at $92^o42'$E and $23^o42'$N.
5. Banana + Bamboo plantation (7 km north-west of Aizawl) located at $92^o40'$E and $23^o44'$N.

6. Tlawng mixed plantation, near Sairang (25 km north west of Aizawl) located at $92^{o}39'$E and $23^{o}50'$N.

7. Paddy field, Khawrihnim, Mamit district located at $92^{o}37'$E and $23^{o}37'$N.

8. Paddy field, Saichal, Champhai district (75 km from Aizawl) located at $93^{o}04'$E and $23^{o}43'$N.

9. Garden of Mustard plantation, N. Hlimen, Kolasib district located at $92^{o}48'$E and $24^{o}13'$N.

10. Lawipu mixed plantation, (5 km west of Aizawl) located at $92^{o}41'$E and $23^{o}43'$N.

11. Tamdil mixed plantation (Lake) area, Aizawl district located at $92^{o}59'$E and $23^{o}40'$N.

Group B:

1. Experimental Site-I, near Sakawrtuichhun (SKT).

2. Experimental Site-II, near Chite stream, within Pachhunga University College campus, (PUC).

Experimental Site-I (SKT)

The experimental site-I (SKT) is set up between Central jail and Sakawrtuichhun village, about 20 km. north west of Aizawl, at an elevation of 650 msl situated at $92^{o}40'$E and $23^{o}45'$N. The temperature ranged between 11^{o}C – 33^{o}C and rainfall from 0 – 628 mm respectively. The top soil is clayey-loam, brownish black and acidic. The land is facing (aspect) westward and the slope varies from 40 to 55 per cent. Grasses like *Cylindrica imperata* and *Erianthus longisetosus* occupied the land before clearing to introduce agroforestry system.

Experimental Site-II (PUC)

The experimental site-II (PUC) is situated near Chite stream, down below Zemabawk village, about 10 km from Aizawl at an elevation of 825 msl situated at $92^o 44'$ E and $23^o 43'$ N. The soil is sandy clay/loam and reddish brown in colour with acidic pH. The climatic conditions like temperature and rainfall are similar as in SKT. The land faces north east and the slope varies from 50 to 65 per cent. The land was previously inhabited by a grass, *Cylindrica imperata* and few trees like *Schima wallichii. Albizzia sp., Sapium buccatum.*

In both study Sites SKT and PUC, the plants introduced were – a hedge - *Leucaena leucocephala* (Hawaiian Giant), a horticultural plant - pine apple, a tree - citrus, and a cereal crop - maize in the following combinations (Fig. 3).

Treatment 1: Pine apple + Citrus + *Leucaena leucocephala (*PCL-Control)

Treatment 2: Pine apple + Citrus + *Leucaena leucocephala* (PCL-NPK treated)

Treatment 3: Maize + *Leucaena leucocephala* (ML-Control)

Treatment 4: Maize + *Leucaena leucocephala* (ML-NPK treated)

In both SKT and PUC sites the farm was divided into two big plots, one plot for PCL plantation and the other for ML plantation. Each of these plantations was further divided into two sub plots. One of it was used as control and the other for NPK treatment. Fertilizer treatment was given as per state government agriculture department recommendation in both study sites.

1. PCL plantation: N, P, K (g/plant) in the ratio of 12.2 : 12.2 : 12.0 equivalent to Urea – 16.1 g/plant, DAP (Diammonium phosphate) - 26.5 g/plant and MOP (Muriate of Potash) - 20 g/plant respectively.
2. ML plantation: N, P, K (Kg/ha) in the ratio of 60 : 40 : 40 equivalent to Urea - 38.5 Kg/acre, DAP- 34.7 Kg/acre and MOP – 26.6 Kg/acre respectively.

Leucaena leucocephala plants were grown in a row keeping 5 ft. distance between each row. In between the *Leucaena leucocephala* rows, citrus were planted at a distance of 8 ft. each and Pineapple were planted at a distance of 3.5 ft. each. Weeding was carried out manually when required using a hand hoe.

ML plantation was maintained on one side of PCL plantation with the rows of *Leucaena* in between. Maize crop was raised in a row at distance of 3 ft. each.

Rainfall

Rainfall was recorded using rain gauge in the Department of Agriculture, Govt. of Mizoram. Adding the daily records the monthly and average rainfall were calculated.

Earthworm Sampling

Earthworms were collected from SKT, PUC and other 11 study sites of different agroforestry plantations like - teak, orange, paddy fields of Khawrihnim and Saichal, banana, banana + bamboo, Tlangnuam mixed plantations, Lawipu mixed plantations, Tlawng mixed plantations, Tamdil mixed plantations and Mustard garden of N.Hlimen by random sampling method during the period June 2002 to December 2004. Five random samples of 25×25×30 cm, located at least 5 m apart were taken at monthly intervals as per Tropical Soil Biology and Fertility (TSBF) programme manual (Anderson and Ingram, 1993). Further, during the period June 2003 to December 2004 strata wise analysis of earthworm population at three different depths *viz*., 0 - 10 cm, 10 - 20 cm and 20 - 30 cm were carried out in PCL plantations of SKT and PUC sites. The collections of samples were done in the morning hours (usually before 10:30 a.m.), in the second week of every month. The soil samples were transferred to an enameled tray and the total numbers of worms were recorded by hand sorting and wet sieving method. The earthworms sampled during the period June 2003 to December 2004 in SKT and PUC were segregated for age group studies and were classified into three age classes – Juvenile (<2 mm), Immature (≥2 mm) but lacking spermathecae and adult, for small sized species (Thambi and Dash, 1973), and Juveniles < 4 cm, immature > 4 < 8 cm and adults > 8 cm length (Clitellate), for larger species (Senapati and Dash, 1984; Mishra and Ramakrishnan, 1988).

Random sample collections from different cropping system, plantations and agroforestry fields of four districts of the state were made to know species diversity and distribution. The samples were preserved in 4% formalin for identification of taxa. The identification was done with the expertise of Dr. J.M.Julka, consultant for earthworm identification and vermiculture, Solan, India.

Density and Biomass

Density of earthworm population (individuals/m^2) was calculated under different treatments.

Every month two sets of five individuals of each age class were weighed after removal of gut contents to determine the biomass (Dash and Patra, 1977).

Worm cast production

To determine the rate of worm cast production, the existing casts were removed from a selected area. Average of five casts samples were collected in the next morning in PCL of SKT and PUC. The samples were weighed, and oven dried at 100^oC for 72 h. Later the dried samples were passed through 2 mm mesh sieve for further chemical analysis.

Secondary production

The secondary production P is defined as total amount of tissue substance produce over a particular time period (generally one year) irrespective of whether it has survived to the end of that period or not (Macfeyden, 1967).

$$P = E + \Delta B$$

Where P = production, E = elimination (biomass of the individuals that have died), ΔB = change in biomass (growth and reproduction)

Secondary production was calculated following the net change in biomass adding with mortality of subsequent months during the period January –

December 2003. The secondary production of different strata of earthworm population was calculated between January – December 2004. The energetic conversion of earthworm tissue was made utilizing the standard value given by Goley (1961) i.e. 19.34kJ/g dry weight.

Method of soil sample collection and estimation of Organic Carbon, phosphorus, Potassium and Nitrogen

Soil Sample Collection

Soil samples were collected at the time of earthworm sampling. Collection of soil samples for analyzing physico-chemical parameters in the five plantations other SKT and PUC was done only during the rainy months. In case of SKT and PUC every month sampling was done in the second week usually before 10:30 a.m. Soil sampling was done strata wise i.e. 0 - 10 cm, 10 - 20 cm and 20 - 30 cm at five positions in each plot, kept in separate plastic bag and were serially registered giving all the necessary information in the information sheets as given below:

Information sheet to accompany soil sample

Sl. No.	Place of collection	Sample No	Depth of collection of samples	Site description
1	2	3	4	5

Soil Sampling and Processing

The samples were air dried, grinded and passed through sieves of fine mesh (0.2 mm) size and kept in an air-tight plastic for further analysis (Ghosh *et al.,* 1983).

Soil Temperature

Soil temperature of different strata (0 - 10 cm, 10 - 20 cm and 20 - 30 cm depth) was measured by using soil thermometer at the time of earthworm sampling.

Determination of pH

The pH of the soil sample was measured as described by Anderson and Ingram (1993). In this method 20 g of fresh soil is taken in a 100 ml beaker to which 50 ml of water is added. The suspension is stirred for 10 minutes and leave to stand for 30 minutes. Then it was stirred again for 2 minutes and the pH of the supernatant liquid was read by using Systronic digital pH meter (Systronics - 355).

Determination of soil moisture

Soil moisture was determined by oven dry basis. 10 g of freshly collected soil was kept in a dry container of known weight (W_1) and later the weight of the soil plus container (W_2) was taken. The weighed soil sample was dried at 105^oC for 2 hours or until the weight stabilized. Then it was cooled in a desiccator and reweighed with its container (W_3). The percentage moisture content was calculated using the following formula (Anderson and Ingram, 1993).

$$\text{Moisture (\%)} = \frac{(W_2 - W_3)}{(W_3 - W_1)} \times 100$$

Where, W_1 = Weight of container,

W_2 = Total weight of fresh soil plus container

W_3 = Dry weight of soil plus container

Soil Organic Carbon : Colorimetric Method

Soil organic carbon was estimated by the Colorimetric method (Anderson and Ingram, 1993). 1 g of grounded soil (<0.15 mm) was weighed in to a labeled 100 ml conical flask (if the soil was dark, or was suspected to be high in organic matter used about 0.5 g). To this 10 ml of 5% potassium dichromate solution was added to completely wet the soil. 20 ml of Sulphuric acid was then added from a fast burette and the mixture was gently swirled, then allowed to cool. Thereafter 50 ml of 0.4% Barium chloride was added and the mixture was swirled thoroughly, and allowed to stand overnight, so as to leave a clear supernatant solution. The blank was run without soil. The clear supernatant solution was then transferred into a colorimeter cuvette and measured the optical density by using photoelectric colorimeter (Systronic Photoelectric Colorimeter 112) at 660 nm after setting the instrument to zero with the blank.

The total organic carbon (%) was calculated as follows:

$$\text{Organic carbon (\%)} = \frac{(K \times 0.1)}{(W \times 0.74)}$$

Where, K = unknowns – mean blank value, W = Weight of soil.

Available phosphorus : Bray's Method No. 1

The available phosphorus was measured by Bray's Method No. 1 (Bray and Kurtz, 1945). 60 ml of the Bray's extractant No. 1 was added to 11 conical flasks (100 ml) in a wooden rack, each containing 5 g measured soil sample. The mixture was shaken for 5 minutes and filtered. 5 ml of the filtrate was extracted with a bulb pipette in a 25 ml measuring flask to which 5 ml of molybdate reagent was added. Thereafter, the mixture was diluted with distilled water to 20 ml. It was thoroughly shaken and 1 ml of stannous chloride working solution was added with a bulb pipette and finally it was filled with distilled water to 25 ml mark and was shaken thoroughly. Then the blue colour developed after 10 minutes was read on the photoelectric colorimeter (Systronic Photoelectric Colorimeter 112) at 660 nm, against a reagent with the blank prepared without soil.

After finding the content of available phosphorus from the standard curve, the available phosphorus was calculated as follows.

If A μg P_2O_5 is read from the curve, then

$$\frac{A}{1{,}000{,}000} \times \frac{50}{5} \times \frac{2{,}000{,}000}{5} \times \frac{453}{453} = 4A(lbs.P_2O_5 / Acre)$$

To convert lbs. per acre to Kg per acre, the result is multiplied by 1.12.

Available Potassium : Flame Photometer method

Available Potassium (K) incorporates both exchangeable and water soluble forms of the nutrient present in the soil. The estimation of exchangeable potassium is determined by Flame Photometer method (Stanford and English, 1949). 5 gm of soil sample is shaken with 25 ml of neutral normal ammonium acetate (pH 7) in a conical flask for 5 minutes and filtered immediately through a dry filter paper (Whatman No.1). First few ml of the filtrate is rejected. Potassium concentration in the extract (filtrate) is determined in the Flame Photometer (CL-361/364) after necessary setting and calibration of the instrument.

The amount of available potassium can be calculated as follows.

$$\text{Available K (Kg/ha)} = R \times \frac{\text{Vol. of the extractant}}{\text{Wt. of soil taken}} \times \frac{2.24 \times 10^6}{10^6}$$

Where R = ppm of K in the extract (obtained from standard curve)

= ppm of K $\times$ 11.2

Nitrogen – Kjeldahl Method

Nitrogen estimation was done by Kjeldahl method following Jackson (1962) using Kel plus nitrogen Auto-analyser (KES 04L, DISTYL-EM). The process for estimation of Nitrogen consists of three phases, *viz.*

1. Digestion
2. Distillation
3. Titration

Digestion Process: During digestion, the complicated Nitrogen compounds are broken into simple structure, thereby releasing Nitrogen in the form of Ammonium radical (NH_4^{+}).

Digestion Procedure:

1 g of soil sample was weighed and transfers it to the digestion tube. To which 10 -15 ml of Con. H_2SO_4 and 5 - 7 g of salt mixture were added. Then the digestion tubes were loaded in to the digester which was already heated to digestion temperature. The block temperature was maintained between 360^oC and 410^oC. Colourless or light green colour indicates the end point of the digestion process.

Distillation Process:

During distillation, the ammonium radicals are converted into ammonia under excess alkali after neutralizing the acid in the digested sample with 40 % NaOH on heating. In DISTEIL-EM, the digested samples are heated by passing steam and the ammonia liberated due to the addition of 40% NaOH is dissolved in 4 % boric acid. The boric acid consisting of ammonia is taken for titration.

Distillation:

The digestion tubes were loaded in to the DISTIL-EM carefully and place the conical flak containing Boric acid (Boric acid mixed with mixed indicator having pink color). Thereafter about 30 - 40 ml of 40% NaOH was added until the color inside the digestion tube becomes dark brown. After setting the time for Distillation (usually 6 minutes), the start button was pressed. The end point of distillation was indicated by the DISTIL-EM as the pink color boric acid turns to colorless and subsequently the sound of distillation totally stop.

Titration:

The distilled off Boric acid was titrated against 0.01 N HCl and the reading was noted down as the end point turns the colorless in to pink.

Calculation for % Nitrogen :

$$\%N = \frac{\text{(Sample titer - blank titer)} \times \text{Normality of HCl} \times 14 \times 100}{\text{sample weight} \times 1000}$$

Water Holding Capacity and Soil Porosity

The water holding capacity (WHC) of soil was determined by Keen Raczkowski Box method by using copper cups of 5.6 cm internal diameter and 1.6 cm height (Piper, 1942). The air dried soil sample was passing through 2mm sieve. Appropriate size of filter paper fitted at the bottom of Keens box was weigh(x). The soil sample was transferred in small lots by means of spatula into the Keens Box gently and uniformly. The box was placed in a trough and allowed to saturate for 24 hours. Then the box was taken out from the tray and left it for a short while to drain excess water. The Box was wiped with a filter paper and weigh (*y*). It was then kept at 105 ^{o}C in an oven to constant weight and then weighs (*z*). To apply a correction for the amount of water absorbed, five filter papers of appropriate size were saturate with water on put over the box, a glass rod was rolled gently over them so as the water was squeeze out. Individual weight of each filter paper was taken and the average weight was calculated (*w*). Then the water holding capacity was calculated by the following formula-

$$WHC(\%) = \frac{y-(z+w)}{z-x} x100$$

Total porosity is calculated from the dry bulk density and the particle density (Anderson and Ingram, 1993) which is assumed to be 2.65 g/cm^3 for most mineral soils. Total porosity was calculated from the bulk density data as follows.

$$\text{Total porosity (\%)} = 1 - \frac{\text{bulk density}}{\text{particle density}} \times 100$$

Bulk density

To measure the bulk density, According to Anderson and Ingram (1993), a surface soil of about 2 cm was removed and the spot was leveled. A 5 cm diameter thin sheet metal tube of known weight (W_1) and volume (V) was droved into the soil. Soil from around the tube was excavated and excess soils were trimmed from both ends of the tube. The soil sample along with the tube was dried at 105^oC for 2 days and weighed (W_2). The bulk density was calculated suing following formula –

Bulk density (Db) = $(W_2 - W_1) / V$

Chapter 4

Results

4.1. Earthworm species composition in mixed cropping, agroforestry and plantations

Earthworm species identified and their distribution from different agroforestry vegetation of Mizoram is given in table 2 and 4 (Photo 4a – 8a). Twelve species of earthworms belonging to three families and five genera were identified in different agroforestry, mixed cropping and plantations. The plant species associated with different plantations, mixed cropping and agroforestry systems and the earthworm species collected are presented in tables 1 and 5. In the present study, among the species collected, one of the species identified as *Eutyphoeus mizoramensis* sp. nov. is a new to science.

All the twelve species of earthworms recorded were found in Aizawl district situated in central part of the State. Five species of earthworms *viz*., *Drawida sp., E. gigas, E. mizoramensis* sp. nov., and the two species of *Perionyx* were recorded from western, Mamit district. In northern, Kolasib district, *Drawida sp., E. gigas, E. mizoramensis* sp. Nov. and *P. excavatus* were recorded, and from eastern, Champhai district, *Drawida sp.* and *P. excavatus* were recorded. Thus, *Drawida sp.* and *P. excavatus* were found in all four districts of State (Table 4).

Ecologically all three types *viz*. epigeic, anecic and endogeic species of earthworms were found in the study area. *Perionyx excavatus* and *P. macintoshi* belongs to epigeic species. All three species of *Eutyphoeus* belongs to endogeic category. All four species of *Drawida*, two species of *Amynthas* and *Metaphire houlleti* are anecic species (Table 2). The vertical distribution of different species of earthworm found in SKT and PUC are presented in table 12.

The distribution of earthworm species in different vegetation is given in Table 3. Maximum number of species was seen in Tlangnuam mixed plantation followed by Teak plantation and Orange plantation. Eight different species of earthworms were recorded from Tlangnuam mixed plantation. Teak plantation and Orange plantation harbored seven species of earthworms. The number of species in Banana, Paddy field of Khawrihnim and PUC was slightly less with five species. Banana + Bamboo, Mustard garden of N. Hlimen and SKT harbored four species of earthworms. Three species were recorded from Lawipu mixed plantation, two species each from Tamdil mixed plantation and Saichal paddy field. Only one species of earthworm was found on the river bank (Tlawng mixed plantation). *Drawida sp.* and *P. excavatus* were observed to be more versatile in their distribution followed by *E. mizoramensis* sp. nov. and *M. houletti.* Three species, *A. alexandri, E. gigas,* and *E. assamensis* were restricted to mixed plantation at Tlangnuam. All four species of *Drawida* recorded were found in Teak plantation. It was noted that soils with course sandy texture harbor lesser earthworms in terms of number and species. There were four common species of earthworm's viz. *P. excavatus, M. houlleti, Drawida sp.* and

E. mizoramensis sp. nov. in both the study sites. In addition *P. macintoshi* was also recorded in PUC in the month of August 2003.

In most of the vegetation earthworms were recorded during rainy months between April and October (Tables 7 - 10). Monthly distributions of earthworms in SKT and PUC have shown that *Drawida sp*., an anecic worm was found through out the year in both SKT and PUC study sites. Except for *Drawida* no other species of earthworms were found in the winter months in both the study sites (Table 10 and Graph 1 & 2). *P. excavatus, M. houletti* and *E. mizoramensis* sp. nov. were found during the rainy period (Table 10).

The Simpson's index of Dominance (D) was 0.5727 for SKT and 0.4863 for PUC. It was found to be highest in the month of June (0.6650) in both the study sites. The Shannon and Weaver's diversity index ($\overline{H}$) was higher in PUC (0.9558) compared to SKT (0.6955). The highest diversity was seen in the month of September 2003 in SKT (1.1220) and in the month of August 2003 (1.3050) in PUC. The D values were higher and $\overline{H}$ values lower in SKT and PUC as compared to other vegetations studied (Table 11).

Among other vegetations studied, the Simpson's index of Dominance (D) was highest in Banana plantation (0.3312) where as the Shannon Weaver's diversity index ($\overline{H}$) was highest in Teak plantation (1.6842) however the index of dominance was lowest in Teak plantation. Banana plantation having highest dominance value recorded least diversity (Table 11).

4.2. Earthworm community structure under different land use and farming practice

The earthworm population dynamics of PCL plantation in SKT and PUC for the period July 2002 to December 2004 is presented in table 13 and graphs 3 and 4. Studies on species-wise density of the two study sites have showed a similar pattern (Table 14 and 15; Graph 5 and 6). The peak density of earthworms in SKT was in the month of October 2002 where as in PUC it was in July 2002. The biomass was greatly reduced in the second and third year of study in both the study sites. The peak biomass of earthworm was observed in September 2003 in SKT and October 2002 in PUC.

The strata-wise density and biomass of earthworm population in PCL plantation of SKT and PUC for the period June 2003 to December 2004 are presented in tables 28 and 29 and graphs 7 – 10. The general pattern of strata wise population density was similar in both SKT and PUC. Maximum density was found in 0 - 10 cm followed by 10 - 20 cm and 20 - 30 cm respectively. A decline in population density in the lower two strata was observed in SKT in the second year of study, while no marked effect was seen in upper strata (Graph 5). During dry periods (March - May) density was higher in 10 - 20 cm depth compared to 0 -10 cm. Though there was not much variation in density of earthworm of different strata in the second year, the biomass decreased enormously.

The density of earthworm was highest in teak plantation whereas (155.16 no/m^2) whereas density was minimum in Banana plantation (22.47 no/m^2) (Table 6).

Biomass of earthworms in SKT was relatively higher as compared to PUC (Graph 4). Biomass in both SKT and PUC was highest in upper soil strata (0 -10 cm) followed by middle strata (10 - 20 cm) and lowest strata (20 - 30 cm) (Graph 9 and 10). However, in dry season (March to May), 10 - 20 cm strata carried higher population biomass as compared to the other two strata (Table 26 and 27). There is a sudden increase in biomass in the month of June 2003 when the monsoon sets in.

The difference in density of adult earthworm population between first and second year of study was higher as compared to juvenile and immature age group. The adult worm showed a peak density in month of June 2003 and highest biomass in the month of September 2003 at SKT where as in PUC the density was at its peak during September – October 2003 and biomass during September 2003. The age-wise seasonal variation in density and biomass of earthworms is given in table 23 and 24. In line with the studies on total density and biomass, even the strata-wise density and biomass were greatly decreased in the second year of study (Graph 3, 4, 7 - 10).

In SKT the peak biomass in 0 - 10 cm reached in August 2003, whereas it was in September 2003 for 10 - 20 cm (Graph 9). In PUC the peak biomass in 0 - 10 cm was seen in the month of September 2003, where as it was in October 2003 for 10 - 20 cm strata (Graph 10).

The number of Juvenile and Immature earthworms collected in the lowest strata (20 - 30 cm) in SKT was negligible as compared to the adults whereas in PUC the immature earthworms were more as compared to adults (Table 30 and graph 11 and 12). In PUC the top soil (0 - 10 cm) had higher juvenile biomass as compared to immature and adult in the month of June - July but reversed in the month of August – September (Graph 13 and 14).

The distribution of different species of earthworm in different land use types like orchards, jhumed cultivation, mixed plantation, river bed, experimental agroforestry plots and the plants associated in each plot are presented in Table 5. It was observed that Tlangnuam mixed plantation with nine different plant species harbors eight species of earthworms while Orange plantation with only two plant species harbors seven different species of earthworm.

The orchards (Orange plantation, SKT and PUC) represented 8 species of earthworm, Jhumed cultivation (Banana plantations, Paddy fields of Khawrihnim and Saichal, Banana+bamboo, Lawipu mixed plantation) harbored 5 species, Forest (Teak plantation) recorded 7 species, Mixed plantations without jhuming (Tlangnuam, Tamdil, Tlawng river bed and N.Hlimen) has 10 different species of earthworms (Table 3). The anecic *Drawida sp.* was found to thrive in varied land use practices mentioned above.

Endogeic species like *Eutyphoeus* was not found in the forest area, where as, all three ecological categories of earthworm (epigeic, anecic and endogeic) were found distributed in orchards, jhumed and mixed plantation areas.

4.3. Impact of soil characteristics and rainfall on the earthworm population dynamics

Among the seven different study sites where detailed soil analysis was carried out, Tlangnuam mixed plantation was found to have highest soil moisture content (24.96 ± 2.8), pH (6.14 ± 0.1), Organic carbon (2.76 ± 1.2) and nitrogen (0.51 ± 0.07). However, SKT had highest C/N ratio with average value of 6.19 followed by PUC with 5.73. The available phosphorus content of soil was highest in Banana plantation (52.89 ± 26.2) and Teak plantation had highest value of available potassium (170.72 ± 32.2). The soils of SKT and PUC recorded the lowest pH (4.9 ± 0.3), and Bamboo + Banana plantation recorded lowest organic carbon (1.16 ± 0.5) and C/N ratio (3.13). Lowest nitrogen content (0.34 ± 0.13) and lowest moisture (19.7 ± 1.8) were found in Banana plantation. Lowest available phosphorus (24.62 ± 9.4) and lowest available potassium (99.65 ± 26.3) were recorded in PUC and Orange plantations respectively (Table 6).

Studies on physical and chemical parameters of the soil were carried out, both in SKT and PUC sites at monthly intervals, from July 2002 – December 2004 and the data is presented in tables 17 – 22 and graphs 15 - 26. It was observed that there was a positive correlation ($P < 0.01$) between soil temperature and moisture in both the study sites, but, there was no significant difference in these physical factors between the SKT site and PUC site, during the study period.

The total density and biomass of earthworm population were higher in rainy months (May - September) when both moisture content and temperature of soil were in relatively high range. Maximum rainfall during the study period was recorded in June 2003 (753 mm) and no rainfall was recorded in winter months. There was a significant correlation ($P < 0.01$) between rainfall and earthworm population density in NPK treated PCL plantation at SKT and PUC where as the control PCL plantation was positively correlated with rainfall only in SKT ($P < 0.01$). No significant correlation was observed between rainfall and earthworm density in NPK treatment of PUC (Table 16).

Highest soil temperature was observed in May 2004 (28.93 ± 0.02) at SKT when the earthworm density was 45 (no/m^2), and in August 2004 (29.89 ± 0.89) at PUC when the earthworm density was 107 (no/m^2). The minimum soil temperature was observed in January 2003 (17.8 ± 0.94) at SKT with earthworm density 42 (no/m^2) and in December 2004 (18.37 ± 0.14) at PUC having earthworm density of 16 (no/m^2) (Table 13 and 17).

Soil moisture content was found to be highest in August 2003 (28.62 ± 0.42) at SKT having earthworm density of 137 (no/m^2) and in October 2002 (28.32 ± 0.88) and September 2003 (28.32 ± 0.70) at PUC with density 96 and 51 (no/m^2) respectively. Minimum soil moisture was recorded in April 2003

(10.77 ± 0.41) at SKT with density 51(no/m^2) where the temperature is 22.1^oC, and in February 2003 (12.29 ± 2.37) in PUC where earthworms are not found, temperature being 19.16^oC.

A significant correlation ($P < 0.01$) was observed between earthworm population density and soil physical characters like moisture and temperature in PCL plantation of SKT (Table 31), whereas earthworm biomass showed significant correlation ($P < 0.01$) with rainfall and soil moisture (Table 31). In ML plantation, there was no significant correlation between earthworm population and any of the soil physical characteristics (Table 35 and 37).

Observations on WHC and bulk density of soil were highest in July 2004 in both SKT and PUC. Porosity of the soil was highest in November 2004 in SKT and March 2004 in PUC (Photo 8b). All these three physical parameters have shown no significant correlation between the density and biomass of earthworm both in PCL and ML plantations of SKT and PUC agroforestry sites.

The seasonal variation in chemical parameters is presented in tables 17 – 19 and graphs 19 – 24. Highest soil pH was observed in the month of August 2002 in SKT (5.39 ± 0.10) while in PUC, highest pH (5.34 ± 0.01) was observed in August 2004. Lowest pH in SKT and PUC was observed in February 2003 (4.75 ± 0.04 and 4.49 ± 0.04 respectively). Inorganic constituents like nitrogen, phosphorous, potassium, and the organic carbon were higher in SKT compared to that of PUC.

Strata-wise soil pH change was measured which shows no definite pattern of pH fluctuation. However, it was observed that during rainy periods usually the surface layer of soil had higher pH. There was a significant correlation between soil pH and earthworm density ($P < 0.05$) in PCL plantation of PUC (Table 32) and ML plantation of SKT (Table 36). No correlation between soil chemical parameters and earthworm biomass was observed in all treatments except potassium in SKT ($P < 0.05$) (Table 34 and 38).

Among the different study sites, the highest organic carbon was recorded from Tlangnuam mixed plantation (2.76 %) and lowest in Banana + Bamboo plantation (1.16 %). The organic carbon was highest in the month of July 2002 both in SKT and PUC (3.43 ± 0.02 and 2.83 ± 0.01 respectively) and lowest in April 2004 (1.32 ± 0.07) in SKT and September 2003 (1.34 ± 0.06) in PUC. There was a significant correlation between earthworm density and soil organic carbon in SKT ($P < 0.05$) (Table 32), but there was no correlation between the organic carbon and biomass in PCL plantations of both sites. Similar observations were recorded even in ML plantations (Table 35 and 38).

The nitrogen content was recorded highest in Tlangnuam mixed plantation (0.51 ± 0.07) and lowest in Banana plantation (0.34 ± 0.13). Soil nitrogen was highest in the month of October 2002 in PCL plantation of both study sites (0.69 ± 0.07 in SKT and 0.56 ± 0.02 in PUC) and lowest in August 2002 (0.16 ± 0) in SKT and August 2002 and December 2005 (0.15 ± 0) in PUC.

In general, the C/N ratio was highest in SKT and lowest in Banana + Bamboo plantation. Maximum C/N ratio in PCL plantation was recorded in August 2002 (19.22 ± 0.72 and 16.87 ± 0.95 in SKT and PUC respectively), and minimum was observed in April 2004 (2.54 ± 0.16) at PCL plantation of SKT and in September 2003 (2.85 ± 0.08) at PUC (Table 18). C/N ratio showed significant correlation ($P < 0.01$) with earthworm density only in PCL plantation of PUC (Table 32).

Maximum value of available phosphorus in PCL plantations were recorded in August 2002 (86.01 ± 10.73) at SKT and in August 2004 (50.76 ± 5.29) at PUC, whereas lowest value was observed in December 2003 (8.71 ± 1.31) and in January 2004 (4.48 ± 1.12) at SKT and PUC respectively (Table 19). Phosphorus shows a significant correlation only with earthworm density in SKT ($P < 0.01$) (Table 32).

Available potassium was highest in May 2003 (276.64 ± 33.50) in SKT PCL plantations and in April 2003 (167.45 ± 11.04) in PUC. But the least value observed in December 2004 in both SKT (31.24 ± 1.36) and PUC (19.78 ± 0.37). Available potassium has a significant correlation with earthworm biomass in SKT PCL plantation ($P < 0.05$) (Table 34).

The density of earthworm increased along with physical parameters like rainfall and soil moisture content both in SKT and PUC (Graph 27 and 29). Density of earthworm also increased along with chemical parameters like potassium, C/N ratio and Phosphorus with few exceptions in some months (Graph 28 and 30).

The nutrient contents in the soil of SKT were noted to be higher than the soil of PUC (Table 6). The co-efficient of correlation (r) of worm density and biomass with soil characteristics were calculated in PCL and are presented in Table 31 - 34. The density of earthworm population was seen to be significantly correlated ($P < 0.01$) with physical parameters like rainfall, soil temperature and soil moisture in both SKT and PUC. Chemical parameters like organic carbon and available phosphorus were correlated with density in the soil of SKT whereas, pH ($P < 0.05$), and C/N ratio ($P < 0.01$) were positively significantly correlated with density in the soil of PUC. However, nitrogen had a negative correlation ($P < 0.01$) with density in PUC.

The co-efficient of correlation (r) of worm density and biomass with soil characteristics were also calculated in ML plantation, presented in table 35 - 38. Except on density with pH ($P < 0.05$) in SKT, none other chemical parameters were found to be to be correlated in both study sites.

4.4. Secondary production of earthworm population

The total biomass in SKT was more than double compared to PUC. It reached maximum in the month of September 2003. It was negligible in winter months with minimum in the month of February.

It was observed that the secondary production reduced significantly during 2004. The total secondary production was found to be higher in SKT (2003 = 2425 and 2004 = 335 $KJ/m^2/yr$) as compared to PUC (2003 = 2261 and 2004 = 239 $KJ/m^2/yr$).

The secondary production on different strata of population has shown that the earthworm found in the top soil (0 – 10 cm) contributed to 60%. It was followed by the second strata (10 – 20 cm) which was about 30% and third strata (20 – 30 cm) which was about 10% (Table 25).

4.5. Worm cast production and its nutrient status in relation to adjacent soil

Studies on worm casts were done in PCL plantation of SKT and PUC in three subsequent years from 2002 to 2004. The results are presented in tables 39 – 43 and graphs 31 – 35. The general observation was that the worm casts were found during seven months of the year (May - November). It was recorded only in the month of August in the third year of the study (2004) from PUC. *Eutyphoeus* an endogeic, which is bigger in size compared to other species, produced cast heap up to 2 - 5 cm (Photo 7b) where as epigeic species like *P. excavatus* produces small granular casts (Photo 7c).

Among the cast collected sites, Tlangnuam mixed plantation recorded highest production rate while PUC, Banana plantation and Banana + Bamboo plantations were categorized as very poor production sites (Table 40).

The total cast production was higher in SKT compared to PUC and it was higher in the first year of study compared to second and third years. In SKT cast production was highest in October 2002 (3498.27 ± 46.88 kg/ha) and lowest in June 2004 (45.96 ± 3.57 kg/ha). PUC has its maximum worm cast in July 2003 (565.10 ± 16.75 kg/ha) and minimum production in September 2003 (123.78 ± 7.11 kg/ha) (Table 39). There was no significant correlation between worm cast production and earthworm population in PCL plantations of SKT and PUC (Table 42).

In general, the moisture content, pH, organic carbon and inorganic nutrients like phosphorus and potassium were higher in worm casts compared to adjacent soil significantly in all three years of study ($P < 0.05$) (Graph 31 - 35). There was no significant difference between the nitrogen of worm cast and adjacent soil, except in PUC during the year 2002. Also that, the moisture content and pH in 2003 at PUC and phosphorus in 2002 at SKT and PUC showed no significant variation between worm cast and adjacent soil. In particular, available potassium, organic carbon, pH and moisture content showed highly significant difference ($P < 0.01$) between worms cast and adjacent soil in both sites throughout the study period.

In the present study no correlation was found between worm cast production and soil chemical properties except for phosphorus in PUC (Table 43).

4.6. Effect of fertilizer (NPK) on earthworm population

The effect of NPK on the population of earthworms was carried out in PCL plantations and in ML plantations in both SKT and PUC sites. In general NPK application showed a trend of increased population density both in PCL and ML plantations (Tables 44 and 45).

The trends in changes of population density in control and on NPK treatment between SKT and PUC were positively correlated (r = 0.860 and r = 0.822 respectively). The density of earthworms in SKT was higher than in PUC in both PCL and ML plantations. The effect of NPK application on the density is shown in graph 36 for PCL plantation and graphs 37 and 38 for ML plantation in both study sites.

Four species of earthworms *viz. Drawida sp. M. houletti, P. excavatus,* and *E. mizoramensis* were found in PCL plantation of both study sites. *P. macintoshi* was found only in PUC. The density of earthworms ranged from 16 to 186 no/m^2 in control and 16 to 368 no/m^2 in NPK treated of SKT. The density of earthworms ranged from 3.2 to 156.6 no/m^2 in control and 6.4 to 165.33 no/m^2 in NPK treated of PUC. The population turnover (Maximum population : minimum population) in PCL plantations of SKT control and NPK treated indicated greater population fluctuation in treated. The population turnover in PCL plantation of PUC control and NPK treated indicated that population fluctuation in control.

P. excavatus and, M. houletti indicated increasing trend in population density in both SKT and PUC. Whereas, *Drawida* sp. and *E. gigas* increased only in SKT. However, *Drawida sp.* and *E. gigas* showed a decreasing trend in population density at PUC.

Four species of earthworms *viz. Drawida sp. M. houletti, P. excavatus,* and *E. mizoramensis* were found in ML plantations of both study sites. The density of earthworms ranged from 6.4 to 186 no/m^2 in control and 66 to 201 no/m^2 in NPK treated of SKT. The density of earthworms ranged from 32 to 67 no/m^2 in control and 42 to 75 no/m^2 in NPK treated of PUC. The population turnover (Maximum population : minimum population) in ML plantation of SKT control and NPK treated indicated greater population fluctuation in treated. The population turnover in ML plantation of PUC control and NPK treated indicated greater population fluctuation in control.

Drawida sp. indicated increasing trend in the population density of both SKT and PUC, whereas, *P. excavatus* population increased only in SKT and *M. houletti* showed increase only at PUC. *M. houletti* and *E. gigas* showed a decreasing trend in population density at SKT, while *P. excavatus* showed a decreasing trend in PUC.

One-Way Analysis of variance (ANOVA) was employed to calculate the influence of fertilizer on earthworm population (Table 46 - 49). There was a significant variation ($P < 0.05$) in Juvenile population between Control and NPK treatment at 0 - 10 cm depth in PCL of SKT whereas in PUC, variation was observed at 10 - 20 cm depth ($P < 0.01$).

In ML plantation of SKT, there was no variation in juvenile population between Control and NPK treatment, whereas, ML plantation of PUC showed a significant variation ($P < 0.05$) at a surface layer (0 - 10 cm).

Immature population showed a significant variation ($P < 0.05$) between Control and NPK treatment at 10 - 20 cm depth in of PCL plantations of SKT. Similarly, significant variation was observed between Control and NPK treatment at 0 - 10 cm ($P < 0.05$) in PCL plantations and of 20 - 30 cm ($P < 0.01$) depth of PUC. There was no variation in immature population of ML plantation of both the study sites in different soil strata.

Significant increase was observed in adult populations between Control and NPK treatment at 0 - 10 cm and 10 - 20 cm depth in PCL plantations at $P < 0.05$ and $P < 0.01$ levels respectively in SKT, while there was no significant change in the adult population in PCL plantations of PUC and in the adult population of earthworm in ML plantation in all soil strata of both study sites.

4.7. New record of earthworm species

Out of 12 earthworm species (*Amynthas alexandri, A. cortices, Drawida sp., D. nagana, D. nepalensis, D. rangamatiana, Eutyphoeus assamensis, E. gigas, E. mizoramensis sp. nov., Metaphire houletti, Perionyx excavatus* and *P. macintoshi*) only one species (*E. gigas*) was reported earlier. Present study has added knowledge about one new species, *Eutyphoeus mizoramensis. sp. nov*., belonging to family Octochetidae, to the modern world.

Place of collection – Mizoram (Sairang)

Altitude – 900 - 1100 m

Habitat - The species inhabits orchards, plantations, agriculture fields and river beds with sandy clay loam soil (pH range of 4.9 - 6.5, moisture 20 - 26%) at 0 - 30 cm depth. It forms 2 - 5 cm high tower-like casts at the soil surface. The name of the species *mizoramensis* is derived from the State Mizoram in which its type locality is located.

Description - ***External:*** Length 160-169 mm, diameter 6 mm, 143–247 segments. Prostomium tanylobic. First dorsal pore at 11/12. Clitellum annular, ⅓xiii-⅓xvii. Setae lumbricine, *aa* = 1.7-2.2 *ab* = 0.7-0.8 *bc* = 1.0-1.3 *cd* = 0.12-0.14 *dd* on segment 12, *aa* = 3.0-3.6 *ab* = 1.2-1.8 *bc* = 1.7-2.3 *cd* = 0.15 *dd* on segment 24. Avestibulate; openings of penisetal follicles in deep fissures on conspicuously protuberant, paired oval male porophores, at *b* lines, on segment 17; male pores paired, minute, each just behind penial setae on posterior lobe of male porophore. Female pores paired, minute, presetal, slightly median to *a* lines, on segment 14. Spermathecal pores paired, transverse slits, at *a* lines, in intersegmental furrow 7/8. Genital markings paired; postsetal, at *aa* or *bb* with median margins touching or close to each other, usually on segments 7, 16, 18, 19, 20, sometimes on 8, 21, 22, 23, 24; at *ab*, usually on segments 10-12, sometimes on 8, 9, 12, 16. Nephridiopores not recognized.

Internal: Pigment greyish. Septa 4/5/6, 8/9-10/11 muscular, 6/7/8 absent. Oesophagus with a large gizzard in a space between septa 5/6 and 8/9 and a pair of discrete hemi-ellipsoidal intramural calciferous glands in segment 12; intestine begins in segment 15; lateral intestinal caeca paired, broadly tubular, in segment 28; median, unpaired, ventral intestinal caeca 17-23, in segments 33-55; supra-intestinal glands 4-5 pairs, in segments 80-87; dorsal typhlosole simple, lamelliform, in segments ½ 27 to 80-84, lateral typhlosoles in segment 28. Dorsal blood vessel single, complete, extending anterior to gizzard into segment 3; last pair of hearts in segment 13. Holandric, testes and male funnels paired, enclosed in annular sacs, in segments 10 and 11; seminal vesicles paired, in segments 9 and 12, those of 12 extend to segments 14-15. Prostates tubular, paired, in segment 17, extending to segment 18. Penial setae ornamented with numerous, short, widely spaced, transverse rows of fine spines, tip pointed and slightly curved on one side, 2.29-2.32 mm long, 44 μ diameter. Spermathecae paired, in segment 8, each with a median and a lateral multiloculate shortly stalked posteriorly directed ental diverticula, each diverticulum opening into duct through a single opening; duct stout, somewhat conical, shorter than ampulla. Genital marking glands sessile, slightly protuberant in to body cavity (Figure 4 – 6). *Eutyphoeus mizoramensis* sp. nov. - 1. Genital region; 2. Penial seta; 3. Spermatheca.

E. *mizoramensis* belongs to a group of *Eutyphoeus* species with spermathecal pores at *ab*, male pores discharging directly on to body surface (avestibulate), holandric arrangement of testes, and short seminal vesicles in segment 12 (not extending beyond segment 20), and a complete dorsal blood vessel. It is distinguished from other species of the group *E*. *manipurensis manipurensis* Stephenson, 1921 and *E*. *hastatus* Gates, 1929.

Table 1: Plants associated under different mixed croppings, agroforestry systems and plantations

Group	Sl. No.	Plantation	Plants Associated
A	1	Teak – *Melia indica*	*Mikania micrantha*
			Eupatorium odoratum
			Grasses
	2	Banana – *Musa balbisiana*	*Manihot esculenta*
			Grasses
			Eupatorium odoratum
			Imperata cylindrical
			Acacia caesis
	3	Bamboo *(Bamboosa sp)* + Banana (*Musa balbisiana)*	*Glycine max*
			Ipomaea betatas
			Ananas comosus
			Vigna catjang
			Psidium sp.
			Artocarpus heterophyllus
	4	Orange – *Citrus aurantium*	*Mikania micrantha*
			Bidens pilosa
	5	Tlangnuam Mixed plantation	*Brassica campestris*
			Vigna catjang
			Zea mays
			Citrus
			Hibiscus exculentus
			Musa balbisiana
			Ananas comosus
			Cucurbita pepo
			Cucumis sativaus
	6	Tlawng Mixed Plantation	*Zea mays*
			Cucurbita pepo
			Cucumis sativaus
			Citullus vulgaris
			Cucumis melo
			Vigna catjang
			Hibiscus esculentus
			Cutrus
	7	Paddy field, Khawrihnim, Mamit district	*Oriza sativa*
			Zea mays
			Capsicum annum
			Vigna catjang
			Dolichos lablab
			Trichosanthes anguina
			Cucamis sativus
	8	Paddy field, Sichal, Champhai district	*Oriza sativa*
			Zea mays
			Cucurbita pepo
			Vigna catjang
			Capsisum frutescens
			Hibiscus esculentus
			Colocasia esculenta
	9	Lawipu Mixed Plantaion	*Oriza sativa*
			Zea mays
			Cajanus cajan
			Citrus
	10	Tamdil Mixed plantation	*Mangifera indica*
			Citrus
			Bamboosa sp.
			Psidium guajava
	11	Mustard Garden, N. Hlimen, Kolasib district	*Brassica campestris*
			Thaseolus vulgaris
			Brassica oleracea Var. capitata
B	1	Experimental Site I(SKT)	*Leucaena leucocephala*
			Ananas cosmosus
			Zea mays
			Cajanus cajan
	2	Experimental Site II(PUC)	*Leucaena leucocephala*
			Ananas cosmosus
			Zea mays
			Cajanus cajan

Table 2: **Morpho-ecological classification and composition of earthworm species under different Family and Genera**

Sl.No.	Families	Genera	Species	Morpho-ecological Classification
1	Megascolecidae	*Perionyx*	*excavatus* Perrier	Epigeic
2			*macintoshi* Stephenson	Epigeic
3		*Metaphire*	*houlleti* Perrier	Anecic
4		*Amynthas*	*alexandri* Beddard	Anecic
5			*cortices* Kinberg, 1867	Anecic
6	Octochaetidae	*Eutyphoeus*	*mizoramensis* sp. nov.	Endogeic
7			*gigas* Stephenson	Endogeic
8			*assamensis* Stephenson	Endogeic
9	Moniligastridae	*Drawida*	sp.	Anecic
10			*rangamatiana* Stephenson	Anecic
11			*nagan* a Gates	Anecic
12			*nepalensis* Michaelsen	Anecic

Table 3: **Distribution of earthworm species in mixed croppings, agroforestry systems and plantations in Mizoram**

Sl. No.	Earthworm species	SK	PU	Tk	Or	Bn	BB	TN	KR	SC	LP	NH	TD	TL
1	*Amynthas alexandri* Beddard	-	-	+	-	-	-	+	-	-	-	-	-	-
2	*Amynthas cortices* Kinberg	-	-	-	+	-	-	+	-	-	-	-	-	-
3	*Drawida sp.*	+	+	+	+	+	+	-	+	+	+	+	+	-
4	*Drawida nagana* Gates	-	-	+	-	-	+	-	-	-	-	-	-	-
5	*Drawida nepalensis* Michaelsen	-	-	+	+	+	-	+	-	-	-	-	-	-
6	*Drawida rangamatiana* Stephenson	-	-	+	+	+	-	+	-	-	-	-	-	-
7	*Eutyphoeus assamensis* Stephenson	-	-	-	-	-	-	+	-	-	-	-	-	-
8	*Eutyphoeus gigas* Stephenson	-	-	-	-	-	-	+	+	-	-	+	-	-
9	*Eutyphoeus mizoramensis* sp. nov.	+	+	-	+	-	-	-	+	-	+	+	-	+
10	*Metaphire houletti* Perrier	+	+	+	+	+	+	-	-	-	-	-	-	-
11	*Perionyx excavatus* Perrier	+	+	+	+	+	+	+	+	+	+	+	+	-
12	*Perionyx macintoshi* Perrier	-	+	-	-	-	-	+	+	-	-	-	-	-
	Total	4	5	7	7	5	4	8	5	2	3	4	2	1

+ = present, - = absent

SK = SKT; PU = PUC; Tk = Teak plantation; Or = Orange plantation; Bn = Banana plantation; BB = Banana + Bamboo plantation; TN = Tlangnuam mixed plantation; KR = Khawrihnim paddy field; SC = Saichal paddy field; LP = Lawipu mixed plantation; NH = N. Hlimen mustard garden; TD = Tamdil mixed plantation; TL = Tlawng mixed plantation.

Table 4: District-wise distribution of earthworm species in Mizoram

Earthworm species	Districts			
	Aizawl	Champhai	Kolasib	Mamit
Amynthas alexandri Beddard	+	-	-	-
A. cortices Kinberg, 1867	+	-	-	-
Drawida sp.	+	+	+	+
D. rangamatiana Stephenson	+	-	-	-
D. nagan a Gates	+	-	-	-
D. nepalensis Michaelsen	+	-	-	-
Eutyphoeus assamensis Stephenson	+	-	-	-
E. gigas Stephenson	+	-	+	+
E. mizoramensis sp. nov.	+	-	+	+
Metaphire houlleti Perrier	+	-	-	-
Perionyx excavatus Perrier	+	+	+	+
P. macintoshi Stephenson	+	-	-	+

+ present, - absent

Table 5: Vegetations associated with earthworm species diversity in different sites of mixed croppings, agroforestry systems and plantations

Site	Species of earthworm	Plantations
SKT	3, 9, 10, 11	1, 2, 3, 4
PUC	3, 9, 10, 11, 12	1, 2, 3, 4, 18
Teak	1, 3, 4, 5, 6, 10, 11	5, 6, 7
Orange	2, 3, 5, 6, 9, 10, 11	5, 16
Banana	3, 5, 6, 10, 11	6, 7, 8, 9, 10
Banana + Bamboo	3, 4, 10, 11	3, 11, 12, 13, 14, 15
TN Mixed Vegetation	1, 2, 5, 6, 7, 8, 11, 12	3, 4, 13, 17, 18, 19, 20, 21, 22
Khawrihnim paddy fld	3, 8, 8, 11, 12	4, 13, 22, 26, 27, 28, 29
Saichal paddy fld	3, 11	4, 26, 21, 13, 19, 30, 31
Lawipu mixed pltn	3, 9, 11	2, 4, 26, 18
N. Hlimen mustard pltn	3, 8, 9, 11	17, 32, 33
Tlawng mixed pltn	3, 8, 9	4, 13, 18, 19, 21, 22, 23, 24,
Tamdil mixed pltn	3, 11	14, 18, 25, 34

***Earthworm species code** (for table 5, 7, 8, 9)

1. *Amynthas alexandri* Beddard
2. *Amynthas cortices* Kinberg
3. *Drawida sp.*
4. *Drawida nagana* Gates
5. *Drawida nepalensis* Michaelsen
6. *Drawida rangamatiana* Stephenson
7. *Eutyphoeus assamensis* Stephenson
8. *Eutyphoeus gigas* Stephenson
9. *Eutyphoeus mizoramensis* sp. nov.
10. *Metaphire houletti* Perrier
11. *Perionyx excavatus* Perrier
12. *Perionyx macintoshi* Perrier

****Plant species code**

1. *Leucena leucocephala*
2. *Cajanus cajan*
3. *Ananas cosmosus*
4. *Zea mays*
5. *Mikania micrantha*
6. *Eupatorium odoratum*
7. *Grasses*
8. *Manihot esculenta*
9. *Cylindrica imperata*
10. *Acacia caesis*
11. *Glycine max*
12. *Ipomaea betatas*
13. *Vigna catjang*
14. *Psidium guajava*
15. *Artocarpus heterophyllus*
16. *Bidens pilosa*
17. *Brassica campestris*
18. *Citrus*
19. *Hibiscus exculentus*
20. *Musa balbisiana*
21. *Cucurbita pepo*
22. *Cucumis sativaus*
23. *Citullus vulgaris*
24. *Cucumis melo*
25. *Mangifera indica*
26. *Oriza sativa*
27. *Capsicum annum*
28. *Dolichos lablab*
29. *Trichosanthes anguina*
30. *Capsisum frutescens*
31. *Colocasia esculenta*
32. *Thaseolus vulgaris*
33. *Brassica oleracea*
34. *Bamboosa sp.*

Table 6: Physico-Chemical analysis of soil and earthworm density under mixed croppings, agroforestry systems and plantations (Mean ± SD)

Study sites	MC (%)	pH	OC (%)	N (%)	P (Kg/ha)	K (Kg/ha)	C/N ratio	Soil type	Density (no/m^2)
SKT	20.78±5.8	4.9 ± 0.3	2.54 ± 0.5	0.41 ± 0.15	39.43 ± 21.8	159.92 ± 54.1	6.19	SCL	86.73
PUC	22.35±5.1	4.9 ± 0.3	2.18 ± 0.3	0.38 ± 0.12	24.62 ± 9.4	105.27 ± 35.2	5.73	CL	52.26
Teak	20.17±2.2	5.86 ± 0.3	1.89 ± 0.5	0.38 ± 0.13	50.34 ± 33.5	170.72 ± 32.2	4.97	L	155.16
Orange	23.64±3.2	5.13± 0.4	1.91 ± 0.3	0.46 ± 0.16	36.83 ± 19.4	99.65 ± 26.3	4.15	SL	88.96
Banana	19.7±1.8	5.3 ± 0.3	1.53 ± 0.4	0.34 ± 0.13	52.89 ± 26.2	161 ± 44.3	4.5	CS	22.47
Banana + Bamboo	21.57±2.0	5.6 ± 0.4	1.16 ± 0.5	0.37 ± 0.09	46.34 ± 13.5	159.6 ± 27.9	3.13	CS	42.4
TN Mixed plantation	24.96±2.8	6.14 ± 0.1	2.76 ± 1.2	0.51 ± 0.07	51.01 ± 13.2	154.56 ± 23.7	5.41	L	108.47

MC - moisture content, SCL - sandy clay loam, L - loam, SL - sandy loam, CS - clayey sandy

Table 7: Status of earthworm species (month wise) in Teak and Orange plantations (July 2002 – June 2004)

Month	Teak Plantation												Orange Plantation											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
J	-	-	-	+	+	-	-	-	-	+	-	-	-	-	-	-	+	+	-	-	+	-	+	-
A	+	-	-	+	+	-	-	-	-	+	+	-	-	+	-	-	-	-	-	-	+	+	+	-
S	+	-	+	+	+	+	-	-	-	+	-	-	-	+	+	-	-	-	-	-	+	+	-	-
O	-	-	+	+	+	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+	+	-	-
N	-	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
J	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A	-	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M	-	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
J	-	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	+	+	-
J	+	-	+	+	+	+	-	-	-	+	+	-	-	-	-	-	+	+	-	-	-	-	-	-
A	+	-	+	+	+	+	-	-	-	+	-	-	-	+	+	-	+	+	-	-	-	+	-	-
S	+	-	+	+	+	+	-	-	-	+	+	-	-	+	+	-	+	-	-	-	-	-	+	-
O	-	-	+	+	+	+	-	-	-	+	+	-	-	+	-	-	-	-	-	-	+	+	+	-
N	-	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
D	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
J	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M	-	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
J	-	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

\+ present, - absent

Table 8: Status of earthworm species (month wise) in Bamboo + Banana and Tlangnuam mixed plantation (July 2002 – June 2004)

Month	Banana+Bamboo Plantation												Tlangnuam Mixed Plantation											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
J	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	+	-	-	-	-	-	-	+
A	-	-	-	+	-	-	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	-	+	+
S	-	-	-	+	-	-	-	-	-	+	-	-	+	+	-	-	+	+	+	+	-	-	+	-
O	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-	+	+	-	+	-	-	-	-
N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
J	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
J	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	+	+	-	-	-	-	-	-
J	-	-	-	+	-	-	-	-	-	+	+	-	+	+	-	-	+	+	-	+	-	-	-	+
A	-	-	-	+	-	-	-	-	-	+	+	-	+	+	-	-	+	+	+	+	-	-	-	+
S	-	-	-	+	-	-	-	-	-	+	+	-	+	-	-	-	+	+	+	+	-	-	-	+
O	-	-	-	+	-	-	-	-	-	+	-	-	+	+	-	-	+	+	+	+	-	-	-	-
N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
J	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
M	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
J	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	+

\+ present, - absent

Table 9: Status of earthworm species (month wise) in Banana plantation (July 2002 - June 2004)

Month	Banana Plantation											
	1	2	3	4	5	6	7	8	9	10	11	12
J	-	-	+	-	-	-	-	-	-	-	+	-
A	-	-	+	-	+	-	-	-	-	-	+	-
S	-	-	+	-	-	-	-	-	-	-	-	-
O	-	-	-	-	-	-	-	-	-	+	-	-
N	-	-	-	-	-	-	-	-	-	-	-	-
D	-	-	-	-	-	-	-	-	-	-	-	-
J	-	-	-	-	-	-	-	-	-	-	-	-
F	-	-	-	-	-	-	-	-	-	-	-	-
M	-	-	-	-	-	-	-	-	-	-	-	-
A	-	-	-	-	-	-	-	-	-	-	-	-
M	-	-	-	-	-	-	-	-	-	-	-	-
J	-	-	+	-	+	+	-	-	-	-	-	-
J	-	-	+	-	+	-	-	-	-	+	+	-
A	-	-	+	-	+	-	-	-	-	-	-	-
S	-	-	+	-	-	-	-	-	-	-	-	-
O	-	-	-	-	-	-	-	-	-	+	+	-
N	-	-	-	-	-	-	-	-	-	-	-	-
D	-	-	-	-	-	-	-	-	-	-	-	-
J	-	-	-	-	-	-	-	-	-	-	-	-
F	-	-	-	-	-	-	-	-	-	-	-	-
M	-	-	-	-	-	-	-	-	-	-	-	-
A	-	-	-	-	-	-	-	-	-	-	-	-
M	-	-	-	-	-	-	-	-	-	-	-	-
J	-	-	-	-	-	-	-	-	-	-	-	-

\+ present, - absent

Table 10: Status of earthworm species (month wise) in SKT and PUC (July 2002 - December 2004)

Month	SKT						PUC				
	1	2	3	4	5		1	2	3	4	5
J	+	+	+	-	-		+	-	-	+	-
A	+	+	+	+	-		+	+	+	+	-
S	-	+	+	+	-		-	+	+	+	-
O	-	+	+	-	-		-	-+	+	-	-
N	-	-	+	-	-		-	-	+	-	-
D	-	-	-	-	-		-	-	-	-	-
J	-	-	+	-	-		-	-	-	-	-
F	-	-	-	-	-		-	-	-	-	-
M	-	-	-	-	-		-	-	-	-	-
A	-	-	+	-	-		-	-	+	-	-
M	-	-	+	-	-		-	-	+	-	-
J	-	+	+	-	-		-	+	+	+	-
J	+	+	+	+	-		+	+	+	+	-
A	+	+	+	+	-		+	+	+	+	+
S	+	+	+	+	-		+	+	+	+	-
O	-	+	+	-	-		-	+	+	-	-
N	-	-	+	-	-		-	-	+	-	-
D	-	-	+	-	-		-	-	+	-	-
J	-	-	+	-	-		-	-	+	-	-
F	-	-	+	-	-		-	-	+	-	-
M	-	-	+	-	-		-	-	+	-	-
A	-	-	+	-	-		-	-	+	-	-
M	-	-	+	-	-		-	-	+	-	-
J	+	+	+	-	-		+	-	+	-	-
J	-	-	+	+	-		-	+	+	-	-
A	-	+	+	+	-		+	+	+	-	-
S	-	+	+	-	-		-	+	+	+	-
O	-	+	+	-	-		-	-	+	-	-
N	-	-	+	-	-		-	-	+	+	-
D	-	-	+	-	-		-	-	+	-	-

+ present, - absent

Table 11: Shannon's ($\overline{H}$) and Simpson's (D) index of mixed croppings, agroforestry systems and plantations

Sl. No.	Plantation	$\overline{H}$	D
1	Teak	1.6842	0.2092
2	Orange	1.4106	0.216
3	Banana	0.8714	0.3312
4	Banana + Bamboo	1.4526	0.2522
5	Tn Mixed plantation	1.4650	0.2634
6	SKT	0.6955	0.5727
7	PUC	0.9558	0.4863

Table12: Species-wise distribution of earthworm in different soil strata

Depth	SKT				PUC				
(cm)	P.e	M.h	D.sp	E.mz	P.e	M.h	D.sp	E.mz	P.m
0-10	+	+	+	+	+	+	+	+	+
10-20	0	+	+	+	0	+	+	0	0
20-30	0	0	+	0	0	0	+	0	0

+ = present

Table 13: Density and biomass of earthworm population in PCL (agroforestry system) at experimental site SKT and PUC

Months	Density (no/m^2)		Biomass (g/m^2)	
	SKT	PUC	SKT	PUC
Jul-02	141	176	346.08	186.72
Aug-02	176	112	466.56	268.8
Sep-02	83	54.4	592.8	92.32
Oct-02	243	96	419.84	391.36
Nov-02	106	9.6	274.88	19.2
Dec-02	38	0	46.08	0
Jan-03	42	3	42.08	1.92
Feb-03	6	0	3.2	0
Mar-03	6	0	4.96	0
Apr-03	54	13	45.28	7.68
May-03	179	102	163.84	68.08
Jun-03	186	156	424	158.88
Jul-03	144	67	417.92	61.6
Aug-03	134	44	530.56	121.76
Sep-03	74	51	677.64	390.92
Oct-03	109	48	236.8	308.16
Nov-03	22	13	43.52	47.04
Dec-03	16	10	22.56	14.72
Jan-04	26	10	23	8.64
Feb-04	29	9	30.72	7.68
Mar-04	29	3	28.32	2.88
Apr-04	58	10	54.08	7.68
May-04	45	32	51.04	16.48
Jun-04	117	101	24.57	5.06
Jul-04	117	70	21.06	10.35
Aug-04	171	107	63.14	32.1
Sep-04	133	133	22.61	34.67
Oct-04	75	101	23.25	33.67
Nov-04	27	21	2.43	4.83
Dec-04	16	16	3.68	0.32

Table 14: Species-wise density (no/m^2) of earthworm under agroforestry system in the study site SKT (June 2003 - December 2004)

Species	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
P. excavatus	0	0	0	3.2	0	0	0	0	0	0	0	0	3.2	0	0	6.4	0	0	0
M. houlleti	90	54	58	26	19	0	0	0	0	0	0	0	9.6	9.6	38	26	13	0	0
Drawida sp.	96	90	77	35	90	22	16	26	29	29	58	45	51	58	64	48	32	16	9.6
E. mizoramensis	0	0	0	9.6	0	0	0	0	0	0	0	0	0	3.2	0	0	0	0	0

Table 15: Species-wise density (no/m^2) of earthworm under agroforestry system in the study site PUC (June 2003 - December 2004)

Species	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
P. excavatus	0	0	0	3.2	0	0	0	0	0	0	0	0	9.6	0	6.4	0	0	0	0
M. houlleti	9.6	26	16	16	9.6	0	0	0	0	0	0	0	16	0	32	26	0	0	0
Drawida sp.	147	38	22	19	38	13	9.6	9.6	9.6	3.2	9.6	32	38	42	26	54	54	13	9.6
E. mizoramensis	0	3.2	3.2	9.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P. macintoshi	0	0	3.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 16: Correlation between earthworm density and rainfall in NPK treated and Control (agroforestry system)

PCL	SKT (NPK Treatment)	0.740**
	PUC (NPK Treatment)	0.428
	SKT (CTRL)	0.785**
	PUC (CTRL)	0.825**
ML	SKT (NPK Treatment)	0.473
	PUC (NPK Treatment)	0.595
	SKT (CTRL)	0.907
	PUC (CTRL)	0.354

Table 17: Seasonal variation of soil temperature, moisture content and pH (Mean + SEM) of agroforestry sites (July 2002 - December 2004)

Month	Temperature (^oC)		Moisture (%)		pH	
	SKT	PUC	SKT	PUC	SKT	PUC
J	20.8 ± 0.53	26.06 ± 0.25	25.46 ± 0.59	25.0 ± 0	5.40 ± 0.09	5.34 ± 0.11
A	23.9 ± 0.15	24.8 ± 0.21	27.04 ± 0.55	23.10 ± 1.87	5.39 ± 0.10	5.29 ± 0.08
S	24.7 ± 0.19	25.5 ± 0.46	23.30 ± 0.65	27.55 ± 0.40	5.34 ± 0.10	5.58 ± 0.06
O	24.6 ± 0.21	22.56 ± 0.19	27.45 ± 0.69	28.32 ± 0.88	5.16 ± 0.08	5.11 ± 0.05
N	22.1 ± 0.07	22.24 ± 0.16	26.07 ± 1.33	27.05 ± 0.38	5.01 ± 0.02	4.92 ± 0.03
D	21.1 ± 0.49	19.9 ± 0.18	19.68 ± 1.34	22.71 ± 0.56	5.03 ± 0.08	4.78 ± 0.02
J	17.8 ± 0.94	18.46 ± 0.36	19.27 ± 0.59	21.29 ± 1.71	4.79 ± 0.03	4.82 ± 0.04
F	19.4 ± 0.15	19.16 ± 0.34	13.88 ± 1.48	12.29 ± 2.37	4.75 ± 0.04	4.49 ± 0.04
M	20.78 ± 0.55	20.44 ± 0.95	13.42 ± 0.89	14.07 ± 0.45	4.83 ± 0.07	4.79 ± 0.03
A	22.1 ± 0.21	23.86 ± 0.17	10.77 ± 0.41	20.44 ± 0.92	4.75 ± 0.04	4.68 ± 0.04
M	23.14 ± 0.11	25.38 ± 0.13	22.25 ± 1.19	26.14 ± 1.77	4.81 ± 0.06	4.77 ± 0.05
J	22.99 ± 0.10	22.28 ± 0.10	16.70 ± 1.11	25.14 ± 0.35	5.31 ± 0.12	4.96 ± 0.12
J	22.96 ± 0.13	23.76 ± 0.17	26.73 ± 2.01	28.24 ± 1.35	5.27 ± 0.08	5.42 ± 0.09
A	23.12 ± 0.22	23.78 ± 0.12	28.62 ± 0.42	27.86 ± 0.60	5.04 ± 0.11	4.92 ± 0.05
S	23.08 ± 0.13	23.78 ± 0.10	27.09 ± 0.87	28.32 ± 0.70	5.23 ± 0.09	5.10 ± 0.07
O	23.47 ± 0.07	23.46 ± 0.05	26.35 ± 3.70	26.14 ± 1.05	5.32 ± 0.07	5.02 ± 0.02
N	22.16 ± 0.08	19.84 ± 0.36	19.65 ± 0.91	20.03 ± 0.77	5.31 ± 0.05	4.91 ± 0.13
D	22.9 ± 0.14	20.01 ± 0.10	21.13 ± 0.67	22.95 ± 0.12	4.92 ± 0.03	4.96 ± 0.02
J	23.08 ± 0.02	22.15 ± 0.06	22.71 ± 0.79	21.74 ± 0.68	5.06 ± 0.02	4.92 ± 0.02
F	18.10 ± 0.24	22.14 ± 0.25	19.46 ± 0.39	19.78 ± 0.9	5.24 ± 0.04	5.14 ± 0.01
M	22.02 ± 0.26	23.7 ± 0.08	18.26 ± 0.57	15.15 ± 1.12	5.38 ± 0.06	5.52 ± 0.02
A	24.14 ± 0.09	23.48 ± 0.05	24.97 ± 0.49	23.61 ± 0.55	4.99 ± 0.04	5.09 ± 0.01
M	28.93 ± 0.02	27.53 ± 0.08	20.04 ± 0.64	21.02 ± 0.69	5.32 ± 0.01	5.15 ± 0.03
J	28.74 ± 0.63	28.81 ± 0.57	24.27 ± 0.64	24.53 ± 0.73	5.30 ± 0.02	5.15 ± 0.02
J	26.03 ± 0.19	29.26 ± 0.64	25.9 ± 0.29	26.51 ± 0.53	5.18 ± 0.02	5.13 ± 0.02
A	28.45 ± 0.29	29.89 ± 0.89	26.41 ± 0.36	25.22 ± 0.16	5.46 ± 0.05	5.34 ± 0.01
S	27.17 ± 0.12	28.4 ± 0.28	24.81 ± 0.38	26.57 ± 0.44	5.28 ± 0.02	5.21 ± 0
O	23.97 ± 0.10	23.91 ± 0.32	23.38 ± 0.22	23.41 ± 0.08	5.09 ± 0.01	5.04 ± 0.02
N	21.65 ± 0.20	20.95 ± 0.10	18.65 ± 0.11	20.54 ± 0.07	5.35 ± 0	4.99 ± 0.01
D	18.66 ± 0.11	18.37 ± 0.14	13.96 ± 0.12	15.85 ± 0.18	4.95 ± 0.01	4.59 ± 0.02

Table 18: Seasonal variation in Organic carbon, Nitrogen and C/N ratio of the soils of agroforestry study sites (Mean ± SEM) (July 2002 - December 2004)

Month	Organic Carbon		Nitrogen		C/N Ratio	
	SKT	PUC	SKT	PUC	SKT	PUC
J	3.43 ± 0.02	2.83 ± 0.01	0.23 ± 0	0.18 ± 0	14.83 ± 0.72	15.72 ± 1.09
A	3.21 ± 0.16	2.53 ± 0.12	0.16 ± 0	0.15 ± 0	19.22 ± 0.72	16.87 ± 0.95
S	1.94 ± 0.03	1.96 ± 0.05	0.2 ± 0	0.30 ± 0.03	9.48 ± 0.60	6.14 ± 0.83
O	2.83 ± 0.10	2.34 ± 0.16	0.69 ± 0.07	0.56 ± 0.02	4.29 ± 0.54	4.17 ± 0.33
N	2.48 ± 0.17	2.29 ± 0.12	0.55 ± 0.02	0.53 ± 0.02	4.71 ± 0.47	4.32 ± 0.34
D	2.32 ± 0.04	2.05 ± 0.20	0.41 ± 0.05	0.39 ± 0.05	6.72 ± 0.45	5.94 ± 0.30
J	2.43 ± 0.15	1.78 ± 0.12	0.4 ± 0.06	0.37 ± 0	7.3 ± 0.88	4.87 ± 0.43
F	1.86 ± 0.07	1.88 ± 0.05	0.45 ± 0.01	0.48 ± 0	4.11 ± 0.23	3.93 ± 0.19
M	2.02 ± 0.09	2.15 ± 0.21	0.52 ± 0.01	0.42 ± 0.05	4 ± 0.29	5.11 ± 0.22
A	2.93 ± 0.28	1.88 ± 0.11	0.42 ± 0.05	0.32 ± 0.08	6.05 ± 0.27	5.87 ± 0.37
M	2.53 ± 0.09	2.15 ± 0.16	0.48 ± 0	0.44 ± 0	5.27 ± 0.17	4.88 ± 0.38
J	2.32 ± 0.16	1.97 ± 0.11	0.49 ± 0.02	0.37 ± 0.05	4.73 ± 0.21	5.05 ± 0.29
J	1.61 ± 0.13	1.48 ± 0.12	0.51 ± 0	0.52 ± 0	3.16 ± 0.28	2.85 ± 0.26
A	2.33 ± 0.02	1.77 ± 0.07	0.52 ± 0.01	0.4 ± 0.03	4.5 ± 0.19	4.42 ± 0.28
S	1.4 ± 0.05	1.34 ± 0.06	0.5 ± 0	0.47 ± 0.01	2.85 ± 0.15	2.85 ± 0.08
O	2.72 ± 0.09	2.94 ± 0.08	0.45 ± 0	0.5 ± 0	6.04 ± 0.14	5.88 ± 0.14
N	1.63 ± 0.05	1.55 ± 0.10	0.53 ± 0	0.5 ± 0	3.08 ± 0.10	3.1 ± 0.16
D	2.06 ± 0.02	2.04 ± 0.02	0.53 ± 0	0.53 ± 0.01	3.98 ± 0.05	3.98 ± 0.18
J	2.38 ± 0.05	1.98 ± 0.10	0.52 ± 0.01	0.5 ± 0.01	4.58 ± 0.1	3.97 ± 0.28
F	2.04 ± 0.07	2.65 ± 0.13	0.49 ± 0	0.48 ± 0	4.17 ± 0.15	5.52 ± 0.21
M	1.88 ± 0.02	2.03 ± 0.07	0.47 ± 0	0.53 ± 0	4.48 ± 0.07	3.83 ± 0.12
A	1.32 ± 0.07	1.49 ± 0.21	0.53 ± 0	0.50 ± 0.01	2.54 ± 0.16	3.23 ± 0.32
M	1.93 ± 0.03	1.81 ± 0.04	0.54 ± 0	0.5 ± 0	3.57 ± 0.09	3.62 ± 0.12
J	1.42 ± 0.07	1.6 ± 0.06	0.52 ± 0.03	0.22 ± 0.01	3.27 ± 0.11	7.61 ± 0.11
J	2.04 ± 0.04	1.78 ± 0.12	0.21 ± 0	0.19 ± 0	9.71 ± 0.30	9.36 ± 0.5
A	2.09 ± 0.04	2.11 ± 0.03	0.23 ± 0.01	0.19 ± 0	9.08 ± 0.21	11.1 ± 0.03
S	2.46 ± 0.05	1.97 ± 0.03	0.22 ± 0	0.19 ± 0	11.71 ± 0.24	10.36 ± 0.45
O	2.09 ± 0.05	1.77 ± 0.08	0.2 ± 0	0.19 ± 0	10.45 ± 0.38	9.31 ± 0.44
N	2.15 ± 0.07	1.87 ± 0.12	0.19 ± 0	0.19 ± 0	11.31 ± 0.39	9.84 ± 0.6
D	1.67 ± 0	1.97 ± 0.01	0.18 ± 0	0.15 ± 0	9.27 ± 0.25	13.13 ± 0.1

Table 19: **Seasonal variation in levels of Potassium and Phosphorus (Kg/ha) in the soils of agroforestry experimental sites (Mean ± SEM) (July 2002 - December 2004)**

Month	Phosphorus (Kg/ha)		Potassium (Kg/ha)	
	SKT	PUC	SKT	PUC
J	63.61 ± 2.19	37.63 ± 3.03	131.04 ± 1.28	73.72 ± 2.96
A	86.01 ± 10.73	26.88 ± 5.10	114.24 ± 2.98	67.2 ± 2.22
S	51.96 ± 11.23	34.04 ± 7.02	134.4 ± 2.54	57.12 ± 3.32
O	16.07 ± 3.82	12.97 ± 2.93	181.44 ± 4.63	90.72 ± 3.35
N	30.91 ± 3.7	37.18 ± 3.03	161.00 ± 2.11	102.48 ± 1.05
D	23.74 ± 2.51	23.74 ± 4.44	112.56 ± 1.05	97.08 ± 1.05
J	22.4 ± 2.12	21.5 ± 3.75	112.5 ± 1.03	100.79 ± 2.11
F	13.88 ± 1.76	9.83 ± 1.64	179.20 ± 15.23	106.4 ± 5.0
M	44.08 ± 3.7	26.81 ± 5.69	184.8 ± 7.37	135.68 ± 16.1
A	43.9 ± 8.41	26.42 ± 11.09	225.36 ± 22.92	167.45 ± 11.04
M	37.17 ± 5.99	19.7 ± 2.68	276.64 ± 33.50	140 ± 11.04
J	26.87 ± 1.63	13.44 ± 3.0	141.94 ± 8.54	85.49 ± 6.42
J	47.78 ± 1.64	16.67 ± 2.41	173.07 ± 15.16	85.74 ± 5.14
A	17.36 ± 1.50	35.83 ± 2.50	138.06 ± 9.86	70.3 ± 2.36
S	14.93 ± 2.27	13.44 ± 1.82	162.14 ± 17.44	131.93 ± 17.82
O	19.9 ± 1.93	15.18 ± 1.85	133.94 ± 0.74	152.69 ± 5.27
N	10.45 ± 1.97	7.21 ± 2.52	119.94 ± 11.19	70.94 ± 2.37
D	8.71 ± 1.31	10.69 ± 2.32	91.46 ± 8.31	61.34 ± 3.77
J	15.18 ± 1.85	4.48 ± 1.12	42.68 ± 3.39	25.14 ± 1.27
F	11.44 ± 1.99	14.68 ± 0.99	128.17 ± 19.53	79.63 ± 4.5
M	9.7 ± 1.49	8.96 ± 1.82	145.0 ± 12.38	83.00 ± 5.46
A	15.43 ± 1.31	21.94 ± 3.07	105.65 ± 7.53	66.07 ± 3.35
M	16.41 ± 1.52	20.81 ± 1.18	92.71 ± 4.5	61.84 ± 4.16
J	16.92 ± 1.67	10.7 ± 1.57	111.75 ± 5.66	65.95 ± 2.9
J	51.02 ± 3.27	20.89 ± 1.86	44.05 ± 2.44	29.86 ± 0.21
A	60.48 ± 3.82	50.76 ± 5.29	75.04 ± 6.96	32.73 ± 0.25
S	29.59 ± 3.43	24.88 ± 2.12	53.72 ± 4.53	28.49 ± 0.07
O	11.69 ± 1.57	13.43 ± 1.94	44.17 ± 2.96	31.97 ± 2.11
N	17.16 ± 3.24	9.45 ± 1.89	36.57 ± 3.68	22.64 ± 1.06
D	13.52 ± 3.43	17.17 ± 2.84	31.24 ± 1.36	19.78 ± 0.37

Table 20: Water holding capacity (WHC) (%) of the two agroforestry study sites (Mean ± SEM)

Month	SKT	PUC
Mar-04	69.76 ± 0.71	69.15 ± 0.66
Apr-04	76.52 ± 1.27	62.89 ± 0.80
May-04	79.44 ± 0.77	79.14 ± 0.64
Jun-04	75.13 ± 0.83	71.09 ± 0.78
Jul-04	89.94 ± 1.04	81.63 ± 1.40
Aug-04	76.8 ± 0.62	66.68 ± 1.18
Sep-04	77.23 ± 0.55	72.91 ± 0.97
Oct-04	67.3 ± 1.10	67.98 ± 0.60
Nov-04	66.41 ± 0.69	70.34 ± 1.22
Dec-04	69.9 ± 0.85	66.09 ± 1.05

Table 21: Soil Porosity (%) of the agroforestry study sites SKT & PUC (Mean ± SEM)

Month	SKT	PUC
Nov-03	57.73 ± 0.94	58.11 ± 0.77
Dec-03	58.49 ± 0.48	59.24 ± 0.35
Jan-04	58.86 ± 0.76	59.62 ± 0.68
Feb-04	57.73 ± 0.68	57.35 ± 0.72
Mar-04	59.62 ± 0.79	62.26 ± 1.17
Apr-04	52.11 ± 0.43	52.83 ± 0.65
May-04	55.09 ± 1.31	55.47 ± 0.80
Jun-04	50.94 ± 0.72	51.18 ± 1.00
Jul-04	57.73 ± 0.85	52.45 ± 0.36
Aug-04	59.62 ± 0.82	56.98 ± 0.95
Sep-04	56.99 ± 1.02	58.11 ± 0.46
Oct-04	61.13 ± 0.95	61.13 ± 0.82
Nov-04	61.89 ± 0.55	55.84 ± 1.00
Dec-04	59.24 ± 0.73	61.12 ± 0.79

Table 22: Bulk Density of the agroforestry study sites SKT & PUC

Month	SKT	PUC
Nov-03	1.12	1.09
Dec-03	1.1	1.08
Jan-04	1.09	1.07
Feb-04	1.12	1.13
Mar-04	1.07	1.007
Apr-04	1.24	1.25
May-04	1.2	1.18
Jun-04	1.3	1.32
Jul-04	1.12	1.26
Aug-04	1.07	1.14
Sep-04	1.14	1.11
Oct-04	1.03	1.03
Nov-04	1.01	1.17
Dec-04	1.08	1.06

Table 23: Variation (month wise) in earthworm density (no./m^2) age-wise in agroforestry sites at SKT and PUC (June 2003- December 2004)

Month	SKT			PUC		
	Juvenile	Immature	Adult	Juvenile	Immature	Adult
Jun-03	192	192	544	400	288	96
Jul-03	96	112	512	176	160	0
Aug-03	160	160	352	96	80	48
Sep-03	48	64	256	48	32	176
Oct-03	128	160	256	16	16	176
Nov-03	16	32	64	16	16	32
Dec-03	0	32	64	0	48	0
Jan-04	48	48	32	16	32	0
Feb-04	16	64	64	0	16	0
Mar-04	32	48	64	16	32	0
Apr-04	64	96	128	48	112	0
May-04	19	11	19	10	22	0
Jun-04	48	37.3	32	42.7	59	0
Jul-04	32	43	43	27	21	21
Aug-04	48	43	59	37	27	43
Sep-04	59	48	27	42.7	48	43
Oct-04	11	37	27	21	11	69
Nov-04	11	11	5	0	5	16
Dec-04	0	5	11	0	16	0

Table 24: **Variation (month wise) of age-wise earthworm biomass (g/m^2) age-wise in agroforestry sites at in SKT and PUC (June 2003- December 2004)**

Month	SKT			PUC		
	Juvenile	Immature	Adult	Juvenile	Immature	Adult
Jun-03	28.8	42.24	353.6	60	63.36	35.52
Jul-03	14.4	24.64	378.88	26.4	35.2	0
Aug-03	24	35.2	471.36	14.4	17.6	89.76
Sep-03	7.2	14.08	656.36	7.2	7.08	376.64
Oct-03	13.44	28.8	194.56	1.92	2.88	362.56
Nov-03	1.92	5.76	16.8	1.92	2.88	42.24
Dec-03	0	5.76	16.8	1.92	2.88	9.92
Jan-04	5.76	7.2	10.24	0	8.64	0
Feb-04	1.92	9.6	19.2	1.92	5.76	0
Mar-04	3.84	7.2	17.28	0	2.88	0
Apr-04	7.68	14.4	32	1.92	5.76	0
May-04	5.84	4.16	46.08	1.92	14.56	0
Jun-04	3.36	7.84	15.36	0.42	4.69	0
Jul-04	0.32	3.41	17.49	0.26	1.7	8.74
Aug-04	0.96	4.32	58.45	0.74	1.88	28.48
Sep-04	1.17	4.32	18.02	0.85	4.32	30.29
Oct-04	0.21	3.36	19.84	0.42	0.85	34.56
Nov-04	0.21	0.74	1.65	0	0.42	4.96
Dec-04	0	0.37	3.3	0	1.28	0

Table 25: **Secondary production of earthworms in PCL agroforestry sites in SKT and PUC**

Year	Strata (cm)	Secondary production (kJ/m^2/yr.)	
		SKT	PUC
Jan. – Dec. 2003	0 -30	2425	2261
Jan. – Dec. 2004	0 -10	226	122.29
	10-20	65.18	102.55
	20-30	43.94	23.61

Table 26: Strata-wise monthly variation of density and biomass of earthworm, temperature moisture content of soil and rainfall at SKT (June 2003-December 2004)

Month	Depth (cm)	Density (No./m^2)	Biomass (g/m^2)	Temperature (°C)	Moisture (%)	Rainfall (mm)
Jun-03	0-10	93	204	23.2 ± 0.17	18.1 ± 1.05	753
	11-20	80	178	23.0 ± 0.17	16.07 ± 1.01	
	21-30	13	41.6	22.76 ± 0.15	14.22 ± 1.23	
Jul-03	0-10	80	214	23.1 ± 0.2	29 ± 2.13	373
	11-20	48	144	22.86 ± 0.2	26.61 ± 1.11	
	21-30	16	59.2	22.76 ± 0.25	24.67 ± 1.61	
Aug-03	0-10	99	367	23.56 ± 0.3	30.03 ± 0.2	368
	11-20	32	143	23.2 ± 0.17	28.5 ± 0.17	
	21-30	3	21.1	22.7 ± 0	27.86 ± 0.3	
Sep-03	0-10	42	343	23.36 ± 0.11	28.61 ± 1.13	533
	11-20	29	295	23.06 ± 0.05	26.88 ± 1.03	
	21-30	3	41	22.8 ± 0.1	25.78 ± 0.73	
Oct-03	0-10	64	145	23.8 ± 0.1	27.78 ± 1.66	135
	11-20	45	92.2	23.5 ± 0.1	26.57 ± 0.4	
	21-30	0	0	23.4 ± 0.05	24.66 ± 0.44	
Nov-03	0-10	0	0	23.23 ± 1.42	20.38 ± 3.79	0
	11-20	19	34.6	21.56 ± 1.38	18.87 ± 0.43	
	21-30	3	8.96	20.66 ± 0.76	19.71 ± 2.74	
Dec-03	0-10	3	2.88	23.9 ± 0.17	22.11 ± 1.6	48
	11-20	10	14.1	22.69 ± 0.49	20.73 ± 2.42	
	21-30	3	5.6	22.46 ± 0.35	20.56 ± 2.03	
Jan-04	0-10	16	10.6	23.43 ± 0.2	23.86 ± 0.83	0
	11-20	10	12.4	23 ± 0.2	20.79 ± 5.17	
	21-30	0	0	22.83 ± 0.11	20.82 ± 5.66	
Feb-04	0-10	19	21.6	18.43 ± 1.05	18.2 ± 2.57	0
	11-20	6	4.32	17.56 ± 1.43	20.5 ± 0.17	
	21-30	3	4.8	18 ± 1.27	19.76 ± 1.11	
Mar-04	0-10	10	6.72	22.7 ± 0.78	16.88 ± 2.68	11.3
	11-20	13	15.4	21.8 ± 0.79	18.09 ± 1.66	
	21-30	6	6.24	21.56 ± 0.81	19.8 ± 3.26	
Apr-04	0-10	19	14.1	24.46 ± 0.25	25.32 ± 2.79	387
	11-20	29	28	24.06 ± 0.32	25.43 ± 0.65	
	21-30	10	12	23.9 ± 0.26	24.17 ± 1.18	
May-04	0-10	10	23.04	29.76 ± 0.25	20.65 ± 2.55	283
	11-20	26	29.24	28.63 ± 0.15	18 ± 1.18	
	21-30	10	4.8	28.36 ± 0.2	21.49 ± 2.96	
Jun-04	0-10	80	16.8	30.9 ± 0.26	26.47 ± 1.02	443
	11-20	32	6.72	28.06 ± 0.51	23.47 ± 1.01	
	21-30	5	1.05	27.26 ± 0.3	22.87 ± 0.65	
Jul-04	0-10	80	20	26.66 ± 0.25	26.65 ± 0.16	643
	11-20	37	9.25	25.93 ± 0.25	25.87 ± 0.51	
	21-30	0	0	25.53 ± 0.37	25.19 ± 0.02	
Aug-04	0-10	107	41.44	29.3 ± 0.2	27.27 ± 0.2	300
	11-20	37	21.7	28.5 ± 0.26	26.78 ± 0.52	
	21-30	0	0	27.56 ± 0.2	25.19 ± 0.31	
Sep-04	0-10	107	18.19	27.53 ± 0.15	25.18 ± 1.86	404
	11-20	27	4.59	27.2 ± 0.26	25.73 ± 1.14	
	21-30	0	0	26.8 ± 0.1	23.52 ± 0.46	
Oct-04	0-10	64	19.84	23.43 ± 0.06	22.97 ± 3.23	157
	11-20	11	3.41	24.03 ± 0.05	24.15 ± 0.93	
	21-30	0	0	23.93 ± 0.28	23.03 ± 0.75	
Nov-04	0-10	16	1.44	22.36 ± 0.68	18.37 ± 1.11	0
	11-20	11	0.99	21.33 ± 0.15	18.75 ± 1.73	
	21-30	0	0	21.26 ± 0.15	18.85 ± 0.55	
Dec-04	0-10	5	1.15	19.07 ± 0.3	13.52 ± 0.18	0
	11-20	11	2.53	18.53 ± 0.11	14.16 ± 0.23	
	21-30	0	0	18.4 ± 0.17	14.22 ± 0.93	

Table 27: Strata-wise monthly variation of density and biomass of earthworm, temperature moisture content of soil and rainfall at PUC (June 2003-December 2004)

Month	Depth (cm)	Density ($No./m^2$)	Biomass (g/m^2)	Temperature (^oC)	Moisture (%)	Rainfall (mm)
Jun-03	0-10	99	101	22.43 ± 0.05	25.78 ± 0.24	753
	11-20	51	50.88	23.0 ± 0	25.36 ± 0.36	
	21-30	6	7.04	22.1 ± 0.17	24.31 ± 0.24	
Jul-03	0-10	45	39.2	24.1 ± 0.1	31.72 ± 0.74	373
	11-20	19	18.88	23.8 ± 0.1	27.59 ± 2.7	
	21-30	3	3.52	23.7 ± 0.1	25.41 ± 0.71	
Aug-03	0-10	38	88.32	24.06 ± 0.03	26.93 ± 0.82	368
	11-20	6	33.44	23.76 ± 0.05	25.64 ± 0.42	
	21-30	0	0	23.46 ± 0.05	24.54 ± 0.53	
Sep-03	0-10	38	254	23.96 ± 0.23	27.53 ± 0.65	533
	11-20	13	137	23.76 ± 0.15	26.05 ± 0.79	
	21-30	0	0	23.56 ± 0.11	25.22 ± 0.74	
Oct-03	0-10	10	37.76	23.7 ± 0.1	28.04 ± 0.45	135
	11-20	26	263.7	23.46 ± 0.05	26.19 ± 0.15	
	21-30	6	65.92	23.23 ± 0.05	24.36 ± 0.68	
Nov-03	0-10	0	0	19.96 ± 1.3	21 ± 1.9	0
	11-20	10	25.92	19.69 ± 1.21	16.39 ± 1.06	
	21-30	3	21.12	19.8 ± 0.96	19.75 ± 2.31	
Dec-03	0-10	10	14.72	20.33 ± 0.15	23.42 ± 0.48	48
	11-20	0	0	19.96 ± 0.15	23.27 ± 0.46	
	21-30	0	0	19.73 ± 0.11	21.64 ± 1.04	
Jan-04	0-10	10	8.64	22.6 ± 0.17	24.18 ± 1.17	0
	11-20	0	0	22.26 ± 0.6	20.88 ± 2.32	
	21-30	0	0	21.6 ± 0.75	20.17 ± 2.06	
Feb-04	0-10	6	5.76	21.96 ± 1.33	19.92 ± 3.73	0
	11-20	3	1.92	22.03 ± 1.2	18.46 ± 0.66	
	21-30	0	0	21.56 ± 1.22	20.93 ± 3.55	
Mar-04	0-10	0	0	24.4 ± 0.26	14.37 ± 0.46	11.3
	11-20	3	2.88	23.9 ± 0.34	14.93 ± 1.43	
	21-30	0	0	23.7 ± 0.26	16.16 ± 3.38	
Apr-04	0-10	0	0	23.66 ± 0.15	23.64 ± 0.49	387
	11-20	10	7.68	23.46 ± 0.15	23.77 ± 1.53	
	21-30	0	0	23.33 ± 0.15	23.42 ± 1.66	
May-04	0-10	19	9.6	28.03 ± 0.51	20.32 ± 0.65	283
	11-20	10	4.8	27.67 ± 0.3	19.3 ± 0.69	
	21-30	3	2.08	27.53 ± 0.25	23.44 ± 7.45	
Jun-04	0-10	53	2.65	30.73 ± 0.32	26.93 ± 0.83	443
	11-20	48	2.4	28.27 ± 0.2	24.12 ± 0.86	
	21-30	0	0	27.43 ± 0.2	22.55 ± 0.42	
Jul-04	0-10	53	7.95	31.4 ± 0.98	28.07 ± 0.83	643
	11-20	16	2.4	28.74 ± 0.43	26.62 ± 0.14	
	21-30	0	0	27.66 ± 0.05	24.85 ± 0.74	
Aug-04	0-10	80	24	32.96 ± 0.72	25.78 ± 0.59	300
	11-20	21	6.3	28.76 ± 0.3	25.08 ± 0.86	
	21-30	5	1.5	28 ± 0.1	24.8 ± 0.72	
Sep-04	0-10	101	26.26	29.36 ± 0.11	26.62 ± 0.57	404
	11-20	27	7.02	28.2 ± 0.1	25.45 ± 0.33	
	21-30	5	1.3	27.66 ± 0.15	23.94 ± 0.76	
Oct-04	0-10	91	33.67	25.03 ± 3.05	23.71 ± 1.98	157
	11-20	11	4.07	23.4 ± 1.9	23.36 ± 0.59	
	21-30	0	0	23.3 ± 1.73	23.18 ± 0.02	
Nov-04	0-10	11	2.75	21.3 ± 1.93	20.46 ± 2.83	0
	11-20	5	1.25	20.9 ± 1.49	20.5 ± 1.31	
	21-30	5	1.25	20.67 ± 1.28	20.89 ± 0.74	
Dec-04	0-10	11	0.88	18.83 ± 0.11	15.35 ± 0.07	0
	11-20	5	0.4	18.33 ± 0.13	15.85 ± 0.02	
	21-30	0	0	17.97 ± 0.02	16.35 ± 0.1	

Table 28: Strata-wise monthly variation of density and biomass of earthworm with variation in chemical components of soil in agroforestry sites at SKT (Mean ± SEM) (June 2003 - December 2004)

Month	Depth (cm)	Density (no./m²)	Biomass (g/m²)	pH	Org. C (%)	N (%)	P (kg/ha)	K (kg/ha)
J	0-10	93	204	5.46 ± 0.06	2.57 ± 0.13	0.55 ± 0.02	34.32 ± 9.07	157.54 ± 19.66
	10-20	80	178	5.36 ± 0.09	2.29 ± 0.13	0.48 ± 0.01	24.62 ± 3.85	139.96 ± 7.06
	20-30	13	41.6	5.13 ± 0.27	2.06 ± 0.28	0.45 ± 0.03	20.16 ± 3.87	128.42 ± 8.25
J	0-10	80	214	5.44 ± 0.1	2.02 ± 0.13	0.53 ± 0.01	56.0 ± 3.87	212.8 ± 27.59
	10-20	48	144	5.26 ± 0.04	1.57 ± 0.2	0.52 ± 0.01	44.8 ± 0.00	157.92 ± 10.26
	20-30	16	59.2	5.18 ± 0.03	1.26 ± 0.15	0.49 ± 0.00	42.55 ± 3.89	148.58 ± 10.99
A	0-10	99	367	5.06 ± 0.1	2.43 ± 0.15	0.55 ± 0.03	22.38 ± 6.7	148.45 ± 27.3
	10-20	32	143	5.01 ± 0.19	2.33 ± 0.08	0.52 ± 0.01	17.92 ± 3.87	140.0 ± 21.36
	20-30	3	21.1	4.86 ± 0.09	2.20 ± 0.07	0.49 ± 0.01	12.69 ± 5.17	124.69 ± 21.08
S	0-10	42	343	5.25 ± 0.09	1.48 ± 0.13	0.51 ± 0.01	22.4 ± 0.00	200.48 ± 18.43
	10-20	29	295	5.23 ± 0.25	1.43 ± 0.07	0.49 ± 0.02	12.69 ± 5.17	154.93 ± 22.12
	20-30	3	41	5.28 ± 0.22	1.34 ± 0.13	0.47 ± 0.01	9.70 ± 5.17	131.78 ± 23.6
O	0-10	64	145	5.5 ± 0.13	2.97 ± 0.27	0.47 ± 0.1	19.29 ± 6.7	134.9 ± 1.55
	10-20	45	92.2	5.34 ± 0.04	2.75 ± 0.19	0.46 ± 0.04	17.92 ± 3.88	133.65 ± 1.29
	20-30	0	0	5.24 ± 0.07	2.57 ± 0.14	0.46 ± 0.01	20.15 ± 7.73	131.41 ± 1.29
N	0-10	0	0	5.3 ± 0.06	2.2 ± 0.21	0.57 ± 0.02	14.93 ± 7.87	148.52 ± 37.6
	10-20	19	34.6	5.38 ± 0.02	1.57 ± 0.08	0.54 ± 0.01	9.70 ± 5.17	115.73 ± 22.55
	20-30	3	8.96	5.27 ± 0.17	1.07 ± 0.23	0.49 ± 0.03	6.72 ± 0.00	95.57 ± 21.2
D	0-10	3	2.88	4.93 ± 0.08	2.43 ± 0.15	0.58 ± 0.00	9.70. ± 5.17	115.73 ± 20.96
	10-20	10	14.1	4.96 ± 0.18	1.98 ± 0.15	0.48 ± 0.02	9.70 ± 5.17	87.36 ± 17.6
	20-30	3	5.6	4.87 ± 0.09	1.97 ± 0.07	0.53 ± 0.01	6.72 ± 0.00	71.31 ± 14.91
J	0-10	16	10.6	5.04 ± 0.09	2.52 ± 0.56	0.58 ± 0.02	15.68 ± 0.00	55.25 ± 3.42
	10-20	10	12.4	5.0 ± 0.02	2.24 ± 0.07	0.51 ± 0.04	11.95 ± 9.05	38.45 ± 4.52
	20-30	0	0	5.16 ± 0.08	2.39 ± 0.21	0.47 ± 0.03	17.92 ± 3.88	34.35 ± 3.93
F	0-10	19	21.6	5.19 ± 0.13	2.47 ± 0.31	0.49 ± 0.02	14.93 ± 7.86	159.41 ± 84.53
	10-20	6	4.32	5.24 ± 0.14	1.97 ± 0.28	0.49 ± 0.01	6.72 ± 0.00	126.56 ± 59.19
	20-30	3	4.8	5.29 ± 0.14	1.70 ± 0.07	0.49 ± 0.03	12.69 ± 5.17	98.56 ± 17.49
M	0-10	10	6.72	5.35 ± 0.4	2.33 ± 0.08	0.48 ± 0.02	12.69 ± 5.17	164.64 ± 42.6
	10-20	13	15.4	5.45 ± 0.27	1.84 ± 0.08	0.47 ± 0.04	9.70 ± 5.17	143.43 ± 36.79
	20-30	6	6.24	5.35 ± 0.2	1.48 ± 0.13	0.48 ± 0.02	6.72 ± 0.00	126.93 ± 35.77
A	0-10	19	14.1	5.1 ± 0.08	1.61 ± 0.13	0.50 ± 0.03	15.68 ± 0.00	121.52 ± 38.8
	10-20	29	28	5.02 ± 0.24	1.3 ± 0.2	0.52 ± 0.02	14.93 ± 7.86	99.12 ± 16.63
	20-30	10	12	5.2 ± 0.06	1.07 ± 0.35	0.55 ± 0.01	15.68 ± 0.00	96.32 ± 3.16
M	0-10	10	23.04	5.37 ± 0.04	2.43 ± 0	0.58 ± 0.01	20.16 ± 2.87	108.64 ± 8.74
	10-20	26	29.24	5.28 ± 0.05	1.7 ± 0.2	0.55 ± 0.005	15.68 ± 0.00	86.24 ± 8.74
	20-30	10	4.8	5.31 ± 0.05	1.66 ± 0.07	0.50 ± 0.05	12.69 ± 5.17	83.25 ± 0.64
J	0-10	80	16.8	5.23 ± 0.09	1.66 ± 0.07	0.55 ± 0.04	20.16 ± 3.87	128.8 ± 3.89
	10-20	32	6.72	5.35 ± 0.12	1.44 ± 0.15	0.52 ± 0.13	14.93 ± 7.86	114.62 ± 8.55
	20-30	5	1.05	5.33 ± 0.07	1.16 ± 0.07	0.49 ± 0.09	15.68 ± 0.00	91.84 ± 4.88
J	0-10	80	20	5.2 ± 0	2.2 ± 0.15	0.22 ± 0.02	58.98 ± 12.93	51.89 ± 2.58
	10-20	37	9.25	5.26 ± 0.05	1.97 ± 0.28	0.22 ± 0.03	44.8 ± 6.72	42.93 ± 6.16
	20-30	0	0	5.1 ± 0.1	1.97 ± 0.28	0.20 ± 0.02	49.28 ± 3.87	37.33 ± 2.81
A	0-10	107	41.44	5.6 ± 0.1	2.38 ± 0.08	0.26 ± 0.02	73.92 ± 6.72	88.48 ± 8.88
	10-20	37	21.7	5.5 ± 0	2.15 ± 0.23	0.24 ± 0.05	56.00 ± 3.87	87.73 ± 9.65
	20-30	0	0	5.3 ± 0.05	1.75 ± 0.13	0.21 ± 0.02	51.52 ± 6.72	48.92 ± 6.14
S	0-10	107	18.19	5.36 ± 0.05	3.01 ± 0.07	0.25 ± 0.005	32.08 ± 5.19	76.45 ± 13.41
	10-20	27	4.59	5.26 ± 0.05	2.51 ± 0.28	0.22 ± 0.01	24.61 ± 7.73	48.89 ± 2.34
	20-30	0	0	5.23 ± 0.05	1.88 ± 0.4	0.18 ± 0.01	32.1 ± 16.81	35.82 ± 1.12
O	0-10	64	19.84	5.13 ± 0.15	2.57 ± 0.27	0.23 ± 0.01	12.96 ± 5.17	50.4 ± 10.66
	10-20	11	3.41	5.03 ± 0.15	1.97 ± 0.33	0.20 ± 0.01	12.69 ± 5.17	45.55 ± 13.9
	20-30	0	0	5.13 ± 0.05	1.75 ± 0.23	0.17 ± 0.01	9.70 ± 5.17	36.57 ± 4.21
N	0-10	16	1.44	5.36 ± 0.05	2.65 ± 0.34	0.21 ± 0.02	24.61 ± 7.73	47.03 ± 15.04
	10-20	11	0.99	5.36 ± 0.11	2.06 ± 0.2	0.20 ± 0.01	17.16 ± 11.25	32.46 ± 3.35
	20-30	0	0	5.33 ± 0.11	1.75 ± 0.23	0.17 ± 0.01	9.70 ± 5.17	30.23 ± 1.15
D	0-10	5	1.15	5.0 ± 0.1	1.79 ± 0.08	0.21 ± 0.03	20.16 ± 16.15	35.85 ± 3.35
	10-20	11	2.53	4.93 ± 0.05	1.75 ± 0	0.17 ± 0.01	9.70 ± 5.17	28.37 ± 1.28
	20-30	0	0	4.93 ± 0.05	1.48 ± 0.13	0.17 ± 0.00	9.70 ± 5.17	28.39 ± 2.61

Table 29: Strata-wise monthly variation of density and biomass of earthworm with variation in chemical components of soil in agroforestry sites at PUC (Mean ± SEM) (June 2003 - December 2004)

Month	Depth (cm)	Density (no./m^2)	Biomass (g/m^2)	pH	Org. C (%)	N (%)	P (kg/ha)	K (kg/ha)
J	0-10	99	101	5.09±0.28	2.29±0.13	0.5±0.04	17.92±3.87	100.42±2.33
	10-20	51	50.88	4.93±0.17	2.02±0.23	0.38±0.07	14.93±7.86	90.72±5.6
	20-30	6	7.04	4.83±0.11	1.57±0.08	0.25±0	6.72±0	64.96±1.12
J	0-10	45	39.2	5.36±0.1	1.79±0.2	0.54±0.01	22.38±6.7	97.81±2.33
	10-20	19	18.88	5.2±0.04	1.42±0.06	0.52±0.01	17.92±3.87	84.74±1.71
	20-30	3	3.52	5.08±0.17	1.24±0.14	0.51±0.01	9.7±5.17	71.3±4.66
A	0-10	38	88.32	4.98±0.05	1.79±0.08	0.49±0.01	42.56±3.87	80.64±3.36
	10-20	6	33.44	4.9±0.01	1.43±0.2	0.43±0.04	35.08±5.19	69.81±3.42
	20-30	0	0	4.79±0.1	1.25±0.08	0.34±0.05	29.85±7.86	60.48±2.24
S	0-10	38	254	5.25±0.12	1.48±0.13	0.51±0.01	15.68±0	172.48±21.86
	10-20	13	137	5.18±0.1	1.34±0.13	0.46±0	9.7±5.17	137.01±9.32
	20-30	0	0	5.07±0.15	1.12±0.07	0.45±0.02	9.7±5.17	86.24±15.06
O	0-10	10	37.76	5.1±0.01	3.23±0.13	0.54±0.01	20.16±3.87	172.1±4.66
	10-20	26	263.7	4.99±0.04	2.92±0.08	0.51±0.01	15.68±0	151.94±7.45
	20-30	6	65.92	4.85±0.05	2.7±0.12	0.47±0.00	9.7±5.17	134.36±2.3
N	0-10	0	0	5.14±0.2	1.75±0.23	0.52±0.03	14.93±7.86	84.03±10.83
	10-20	10	25.92	5.15±0.09	1.57±0.34	0.49±0.03	4.48±3.87	67.2±5.81
	20-30	3	21.12	4.71±0.45	1.34±0.4	0.5±0.05	2.24±3.87	61.6±4.88
D	0-10	10	14.72	4.89±0.13	2.29±0.13	0.57±0.02	14.93±7.86	75.4±14.59
	10-20	0	0	4.89±0.07	1.97±0.07	0.54±0.02	9.7±5.17	60.1±9.78
	20-30	0	0	4.8±0.05	1.88±0.13	0.49±0.03	7.46±7.86	48.53±9.65
J	0-10	10	8.64	4.88±0.04	2.65±0.2	0.54±0.04	6.72±0	28±6.81
	10-20	0	0	4.93±0.11	1.61±0.23	0.49±0.04	4.48±3.87	24.26±2.33
	20-30	0	0	4.94±0.07	1.7±0.5	0.47±0.06	4.87±3.87	23.15±2.34
F	0-10	6	5.76	5.13±0.11	2.38±0.34	0.49±0.03	12.69±5.17	79.89±16.51
	10-20	3	1.92	5.19±0.02	2.47±0.66	0.48±0.03	15.68±0	70.56±6.99
	20-30	0	0	5.11±0.03	3.1±0.93	0.48±0.02	15.68±0	88.48±19.43
M	0-10	0	0	5.54±0.14	2.43±0.15	0.56±0	9.7±5.17	80.76±20.76
	10-20	3	2.88	5.5±0.13	2.11±0.34	0.54±0.02	10.45±9.05	86.61±19.08
	20-30	0	0	5.53±0.02	1.57±0.28	0.5±0.02	6.72±0	81.76±9.76
A	0-10	0	0	5.12±0.03	1.61±0.94	0.45±0.07	17.92±3.87	65.33±10.87
	10-20	10	7.68	5.03±0.15	1.61±0.61	0.47±0.03	17.92±3.87	60.1±5.05
	20-30	0	0	5.13±0.03	1.25±0.43	0.48±0.06	29.66±12.9	72.8±15.87
M	0-10	19	9.6	5.26±0.04	2.65±0.2	0.52±0.08	20.16±3.87	74.29±18.1
	10-20	10	4.8	5.12±0.2	1.61±0.13	0.5±0.01	17.96±3.84	57.12±15.51
	20-30	3	2.08	5.09±0.1	1.17±0.15	0.49±0.01	20.2±3.81	54.13±6.16
J	0-10	53	2.65	5.1±0.1	1.84±0.08	0.25±0.01	12.69±5.17	75.78±6.36
	10-20	48	2.4	5.13±0.05	1.57±0.08	0.22±0.01	12.69±5.17	63.46±2.33
	20-30	0	0	5.23±0.25	1.39±0.07	0.18±0.01	6.72±0	58.61±4.66
J	0-10	53	7.95	5.2±0.1	2.47±0.43	0.22±0.03	26.83±3.85	33.98±1.69
	10-20	16	2.4	5.13±0.05	1.52±0.63	0.19±0.02	17.92±3.87	29.12±1.12
	20-30	0	0	5.06±0.05	1.36±0.28	0.17±0.02	17.92±3.87	26.5±0.64
A	0-10	80	24	5.4±0.1	2.79±0.16	0.2±0.01	66.45±7.86	43.31±1.71
	10-20	21	6.3	5.33±0.11	1.88±0.13	0.21±0.02	53.76±3.87	31.37±1.12
	20-30	5	1.5	5.3±0	1.66±0.07	0.16±0.02	32.08±5.19	23.52±1.12
S	0-10	101	26.26	5.2±0.1	2.47±0.2	0.22±0.01	32.08±5.19	32.46±2.26
	10-20	27	7.02	5.2±0	2.11±0.2	0.19±0.02	22.4±0	26.51±0.65
	20-30	5	1.3	5.23±0.15	1.35±0	0.17±0.01	20.16±3.87	26.5±1.71
O	0-10	91	33.67	5.13±0.05	2.43±0	0.23±0.01	14.93±7.86	45.56±17.49
	10-20	11	4.07	4.96±0.11	1.79±0.63	0.18±0.01	15.68±0	27.97±2.97
	20-30	0	0	5.03±0.11	1.11±0.14	0.16±0	9.7±5.17	22.39±1.11
N	0-10	11	2.75	5.06±0.15	2.61±0.56	0.23±0.01	14.93±7.86	24.6±5.03
	10-20	5	1.25	4.96±0.05	1.66±0.43	0.18±0.02	6.72±0	21.28±2.49
	20-30	5	1.25	4.96±0.05	1.34±0.13	0.17±0.01	6.72±0	21.07±2.12
D	0-10	11	0.88	4.66±0.15	2.33±0.08	0.16±0.01	22.4±0	19.41±3.42
	10-20	5	0.4	4.6±0.26	1.88±0.13	0.15±0	17.16±11.25	19.79±1.71
	20-30	0	0	4.53±0.05	1.71±0.15	0.14±0	11.95±9.05	20.16±2.24

Table 30: Number of different age class earthworms in different soil strata under agroforestry system at SKT and PUC (June 2003- December 2004)

Month	Depth	SKT			PUC		
	(cm)	Juvenile	Immature	Adult	Juvenile	Immature	Adult
Jun-03	0-10	7	6	16	18	8	5
	10-20	5	6	14	7	8	1
	20-30	0	0	4	0	2	0
Jul-03	0-10	6	3	16	9	5	0
	10-20	0	4	11	2	4	0
	20-30	0	0	5	0	1	0
Aug-03	0-10	10	6	15	6	4	2
	10-20	0	4	6	0	1	1
	20-30	0	0	1	0	0	0
Sep-03	0-10	3	2	8	3	2	7
	10-20	0	2	7	0	0	4
	20-30	0	0	1	0	0	0
Oct-03	0-10	6	4	10	1	1	1
	10-20	1	6	6	0	0	8
	20-30	0	0	0	0	0	2
Nov-03	0-10	0	0	0	0	0	0
	10-20	1	2	3	1	1	1
	20-30	0	0	1	0	0	1
Dec-03	0-10	0	1	0	1	1	1
	10-20	0	1	2	0	0	0
	20-30	0	0	1	0	0	0
Jan-04	0-10	3	2	0	0	3	0
	10-20	0	1	2	0	0	0
	20-30	0	0	0	0	0	0
Feb-04	0-10	0	3	3	0	2	0
	10-20	1	1	0	1	0	0
	20-30	0	0	1	0	0	0
Mar-04	0-10	1	2	0	0	0	0
	10-20	0	1	3	0	1	0
	20-30	1	0	1	0	0	0
Apr-04	0-10	4	1	1	0	0	0
	10-20	0	5	4	1	2	0
	20-30	0	0	3	0	0	0
May-04	0-10	0	0	3	2	4	0
	10-20	5	0	3	1	2	0
	20-30	1	2	0	0	1	0
Jun-04	0-10	3	6	6	5	5	0
	10-20	5	1	0	3	6	0
	20-30	1	0	0	0	0	0
Jul-04	0-10	5	6	4	4	3	3
	10-20	1	2	4	1	1	1
	20-30	0	0	0	0	0	0
Aug-04	0-10	7	5	9	7	2	6
	10-20	2	3	2	0	3	1
	20-30	0	0	0	0	0	1
Sep-04	0-10	11	6	3	8	5	6
	10-20	0	3	2	0	4	1
	20-30	0	0	0	0	0	1
Oct-04	0-10	2	5	5	4	2	11
	10-20	0	2	0	0	0	2
	20-30	0	0	0	0	0	0
Nov-04	0-10	2	1	0	0	0	2
	10-20	0	1	1	0	0	1
	20-30	0	0	0	0	1	0
Dec-04	0-10	0	1	0	0	2	0
	10-20	0	0	2	0	1	0
	20-30	0	0	0	0	0	0

Table 31: Correlation Coefficient (r) of earthworm density with different climatic parameters in PCL agroforestry system

Parameters	SKT	PUC
Rainfall	0.646**	0.735**
Soil temperature	0.482**	0.62**
Soil moisture	0.630**	0.562**

Level of significance *P<0.05 **P<0.01

Table 32: Correlation Coefficient (r) of earthworm density with different Chemical components of soil in PCL agroforestry system

Parameters	SKT	PUC
pH	0.359	0.432*
Organic carbon	0.437*	0.211
Nitrogen	-0.022	-0.487**
Phosphorous	0.481**	0.284
Potassium	0.287	-0.192
C/N	0.262	0.538**

Level of significance *P<0.05 **P<0.01

Table 33: Correlation Coefficient (r) of earhworm biomass (g/m^2) with different climatic parameters in PCL agroforestry system

Parameters	SKT	PUC
Rainfall	0.485**	0.375**
Soil temperature	0.091	0.111
Soil moisture	0.531**	0.508**

Level of significance *P<0.05 **P<0.01

Table 34: Correlation Coefficient (r) of earthworm biomass (g/m^2) with different climatic components in PCL agroforestry system

Parameters	SKT	PUC
pH	0.309	0.242
Organic carbon	0.192	0.281
Nitrogen	0.074	0.122
Phosphorous	0.335	0.017
Potassium	0.362*	0.296
C/N	0.095	0.085

Level of significance *P<0.05 **P<0.01

Table 35: Correlation Coefficient (r) of earthworm density with different climatic parameters in ML agroforestry system

Parameters	SKT	PUC
Rainfall	-0.726	-0.3
Soil temperature	0.14	-0.178
Soil moisture	0.461	0.712

Level of significance *P<0.05 **P<0.01

Table 36: Correlation Coefficient (r) of earthworm density with different Chemical components of soil in ML agroforestry system

pH	0.961*	0.095
Organic carbon	0.722	0.919
Nitrogen	-0.343	-0.738
Phosphorous	0.639	0.516
Potassium	0.689	-0.677
C/N	0.153	0.894

Level of significance *P<0.05 **P<0.01

Table 37: Correlation Coefficient (r) of earthworm biomass (g/m^2) with different climatic parameters in ML agroforestry system

Parameters	SKT	PUC
Rainfall	-0.804	-0.438
Soil temperature	0.253	-0.501
Soil moisture	0.298	0.496

Level of significance *P<0.05 **P<0.01

Table 38: Correlation Coefficient (r) of earthworm biomass (g/m^2) with different Chemical components of soil in ML agroforestry system

pH	0.942	-0.254
Organic carbon	0.604	0.699
Nitrogen	-0.22	-0.782
Phosphorous	0.507	0.253
Potassium	-0.571	-0.28
C/N	0.026	0.777

Level of significance *P<0.05 **P<0.01

Table 39: Cast production (Kg/ha)(2002-2004) in PCL agroforestry system of SKT and PUC (Mean ± SEM)

SKT(02)	PUC(02)	SKT(03)	PUC(03)	SKT(04)	PUC(04)
N.A	N.A	N.A	N.A	98.11 ± 4.62	N.A
N.A	N.A	403.64 ± 13.22	145.31 ± 12.24	45.96 ± 3.57	N.A
N.A	N.A	1506.94 ± 50.30	565.10 ± 16.75	672.74 ± 17.40	N.A
3471.36 ± 76.76	559.72 ± 11.61	618.92 ± 20.59	199.13 ± 8.61	363.28 ± 8.88	261.02 ± 5.06
2378.82 ± 53.18	269.09 ± 7.23	683.50 ± 17.16	123.78 ± 7.11	553.48 ± 19.24	N.A
3498.27 ± 46.88	193.75 ± 9.07	430.55 ± 14.41	N.A	N.A	N.A
230.45 ± 10.90	N.A	N.A	N.A	N.A	N.A

Table 40: Qualitative production of worm cast in mixed cropping, agroforestry systems and plantations

Plantations	Wormcast production
SKT	++
PUC	+
Teak	+++
Orange	+++
Banana	+
Bamboo+Banana	+
TN Mixed plantation	++++
Lawipu Mixed pltn	+++
Saichal paddy	+
Khawrihnim paddy	+++
N.Hlimen mustard	+++

***Worm cast production category**

+ Very poor production

++ Poor production

+++ Moderate production

++++ Intense production

Table 41: **Values of 't' (calculated for physico-chemical parameters) of worm casts and adjacent soil**

Year	Site	Moisture content	pH	Org. C	N	P	K
2002	SKT	-	8.972**	-	1.241	0.048	3.099*
	PUC	-	10.651**	-	3.873*	0.965	7.826**
2003	SKT	9.153**	3.154*	15.178**	2.597	2.979*	2.955*
	PUC	2.672	1.529	7.465**	0.103	4.016*	13.593**
2004	SKT	14.629**	9.740**	6.176**	2.249	5.676**	4.240**
	PUC	-	-	-	-	-	-

Level of significance *P<0.05 **P<0.01

Table 42: **Correlation co-efficient (r) between worm cast production (Kg/ha) and earthworm population in PCL agroforestry system**

Parameters	2002		2003		2004	
	SKT	PUC	SKT	PUC	SKT	PUC
Density	0.68	0.565	0.014	-0.203	0.44	-
Biomass	0.6	-0.092	0.095	-0.658	-0.353	-

Level of significance *P<0.05 **P<0.01

Table 43: **Correlation Coefficient (r) between worm cast production and soil chemical components in PCL agroforestry system**

Parameters	SKT	PUC
Cast production and Org. Carbon	-0.635	-0.305
Cast production and Nitrogen	0.487	0.749
Cast production and Phosphorus	0.076	0.970*
Cast production and Potassium	0.064	-0.318
Cast production and C/N ratio	-0.305	-0.495

Level of significance *P<0.05 **P<0.01

Table 44: Effect of NPK treatment on density of earthworm species in PCL agroforestry system (June 2003 – December 2004)

	SKT								PUC									
	Control				NPK treatment				Control					NPK treatment				
Sp. Code	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4	5
J	0	89.6	96	0	0	67.2	80	0	0	9.6	147	0	0	0	22.4	86.4	0	0
J	0	54.4	89.6	0	0	60.8	76.8	0	0	25.6	38.4	3.2	0	6.4	28.8	54.4	0	0
A	0	57.6	76.8	0	12.8	70.4	73.6	0	0	16	22.4	3.2	3.2	6.4	35.2	25.6	3.2	0
S	3.2	28.8	32	9.6	12.8	41.6	51.2	6.4	6.4	16	19.2	9.6	0	16	48	35.2	0	0
O	0	19.2	89.6	0	0	25.6	89.6	0	0	9.6	38.4	0	0	0	25.6	57.6	0	0
N	0	0	22.4	0	0	0	41.6	0	0	0	12.8	0	0	0	0	22.4	0	0
D	0	0	16	0	0	0	25.6	0	0	0	9.6	0	0	0	0	12.8	0	0
J	0	0	25.6	0	0	0	35.2	0	0	0	9.6	0	0	0	0	12.8	0	0
F	0	0	28.8	0	0	0	35.6	0	0	0	9.6	0	0	0	0	9.6	0	0
M	0	0	28.8	0	0	0	25.6	0	0	0	3.2	0	0	0	0	6.4	0	0
A	0	0	57.6	0	0	0	54.4	0	0	0	9.6	0	0	0	0	22.4	0	0
M	0	0	44.8	0	0	0	41.6	0	0	0	32	0	0	0	0	38.4	0	0
J	5.33	16	96	0	0	245	123	0	16	26.7	64	0	0	21.3	0	90.7	0	0
J	0	16	96	5.3	0	58.7	90.7	10.7	0	0	69.3	0	0	0	21.3	58.7	0	0
A	0	64	107	0	0	90.7	112	0	10.7	53.3	42.7	0	0	0	90.7	26.7	0	0
S	10.7	42.7	80	0	5.33	85.3	107	0	0	42.7	90.7	0	0	16	58.7	85.3	5.33	0
O	0	21.3	53.3	0	0	10.7	42.7	0	0	0	90.7	0	0	0	0	42.7	0	0
N	0	0	26.7	0	0	0	32	0	0	0	21.3	0	0	0	0	21.3	0	0
D	0	0	16	0	0	0	16	0	0	0	16	0	0	0	0	10.7	0	0

*** Earthworm species code** (for table 44 and 45)
1. *P. excavatus*, 2. *M. houletti*, 3. *Drawida sp.*, 4. *E. mizoramensis* sp. nov., 5. *P. macintoshi*

Table 45: Effect of NPK treatment on density of earthworm species in ML agroforestry system (June 2003- December 2004)

	SKT								PUC									
	Control				NPK treatment				Control					NPK treatment				
Sp. Code	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4	5
Jun. 2003	0	89.6	96	0	0	67.2	134	0	0	19.2	48	0	0	0	9.6	32	0	0
Jul. 2003	0	32	70.4	0	0	44.8	60.8	0	0	9.6	35.2	0	0	0	12.8	28.8	0	0
Aug. 2003	0	6.4	122	0	0	0	83.2	0	0	3.2	48	0	0	0	0	48	0	0
Sep. 2003	3.2	16	44.8	0	6.4	22.4	38.4	0	0	16	35.2	0	0	0	19.2	38.4	0	0
Jun. 2004	0	80	10.7	0	5.33	21.3	90.7	0	0	0	32	0	0	0	10.7	64	0	0
Jul. 2004	16	42.7	53.3	0	21.3	53.3	58.7	0	0	0	42.7	0	0	0	5.33	48	0	0
Aug. 2004	0	69.3	101	5.33	0	53.3	112	0	5.33	42.7	0	0	0	0	42.7	10.7	0	0
Sep. 2004	0	42.7	123	0	0	53.3	123	0	0	16	42.7	0	0	0	21.3	42.7	0	0

Table 46: ANOVA of different age group of earthworm with density in SKT agroforestry sites

Earthworm	Source of variation	0-10 cm	10-20 cm	20-30 cm
		F-ratio	F-ratio	F-ratio
Juvenile	CTRL X NPK (PCL)	12.937*	2.509 NS	0
	CTRL X NPK (MAIZE)	0.4 NS	0.25 NS	NA
Immature	CTRL X NPK (PCL)	1.005 NS	5.841*	0.083 NS
	CTRL X NPK (MAIZE)	20.273 NS	0	NA
Adult	CTRL X NPK (PCL)	23.621*	9.75**	0.692 NS
	CTRL X NPK (MAIZE)	0	0.000	NA

Level of significance *P<0.05 **P<0.01, NS = not significant

Table 47: ANOVA of different age group of earthworm with density in PUC agroforestry sites

Earthworm	Source of variation	0-10 cm	10-20 cm	20-30 cm
		F-ratio	F-ratio	F-ratio
Juvenile	CTRL X NPK (PPC)	39.977 NS	11.492**	0
	CTRL X NPK (MAIZE)	699.582*	0.25 NS	NA
Immature	CTRL X NPK (PPC)	5.329*	1.114 NS	18.519**
	CTRL X NPK (MAIZE)	0.02 NS	0.25 NS	NA
Adult	CTRL X NPK (PPC)	90.278 NS	1.663 NS	4.167 NS
	CTRL X NPK (MAIZE)	2.776 NS	0	NA

Level of significance *P<0.05 **P<0.01, NS = not significant

Table 48: ANOVA of earthworm species-wise effect of NPK treatment in PCL agroforestry sites

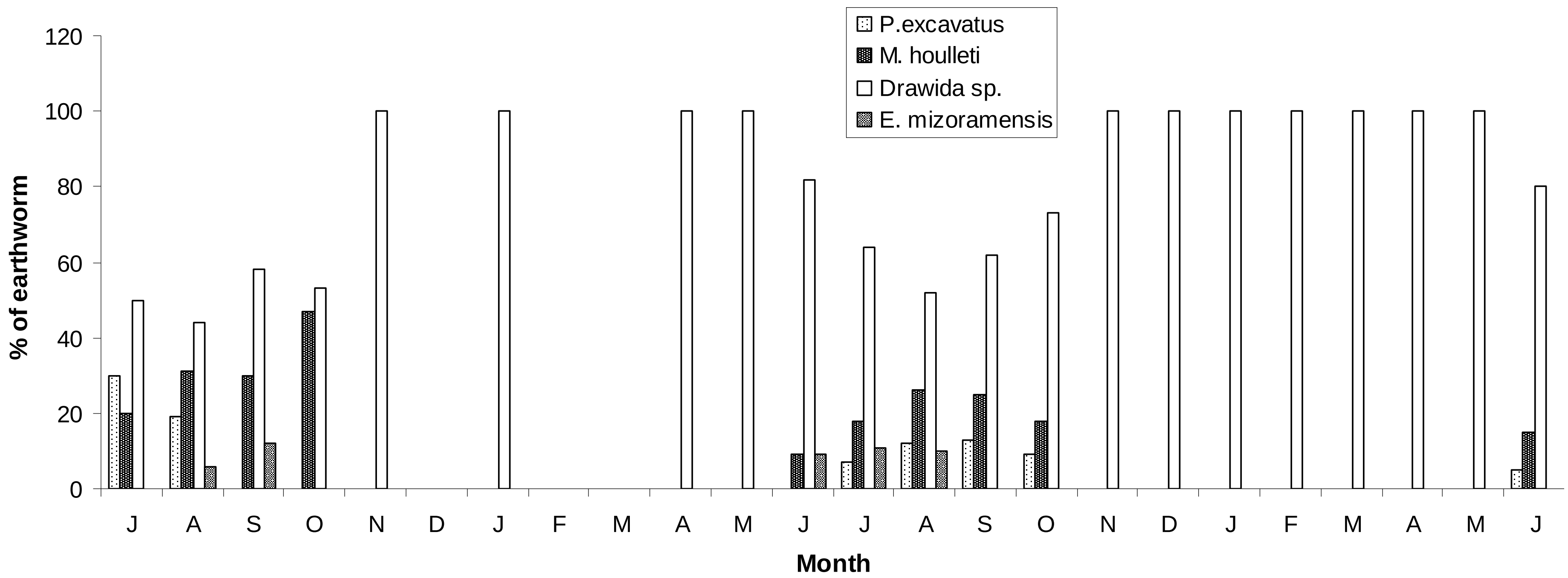
Earthworm species	Source of variation	SKT	PUC
		F-ratio	F-ratio
Perionyx excavatus	CTRL X NPK (PCL)	25.679**	6.729**
Metaphire houletti	CTRL X NPK (PCL)	0	6.951**
Drawida sp.	CTRL X NPK (PCL)	6.993^{NS}	615.718**
Eutyphoeus mizoramensis	CTRL X NPK (PCL)	0	0.913
Perionyx macintoshi	CTRL X NPK (PCL)	**NA**	0

Level of significance *P<0.05 **P<0.01, NS = Not significant

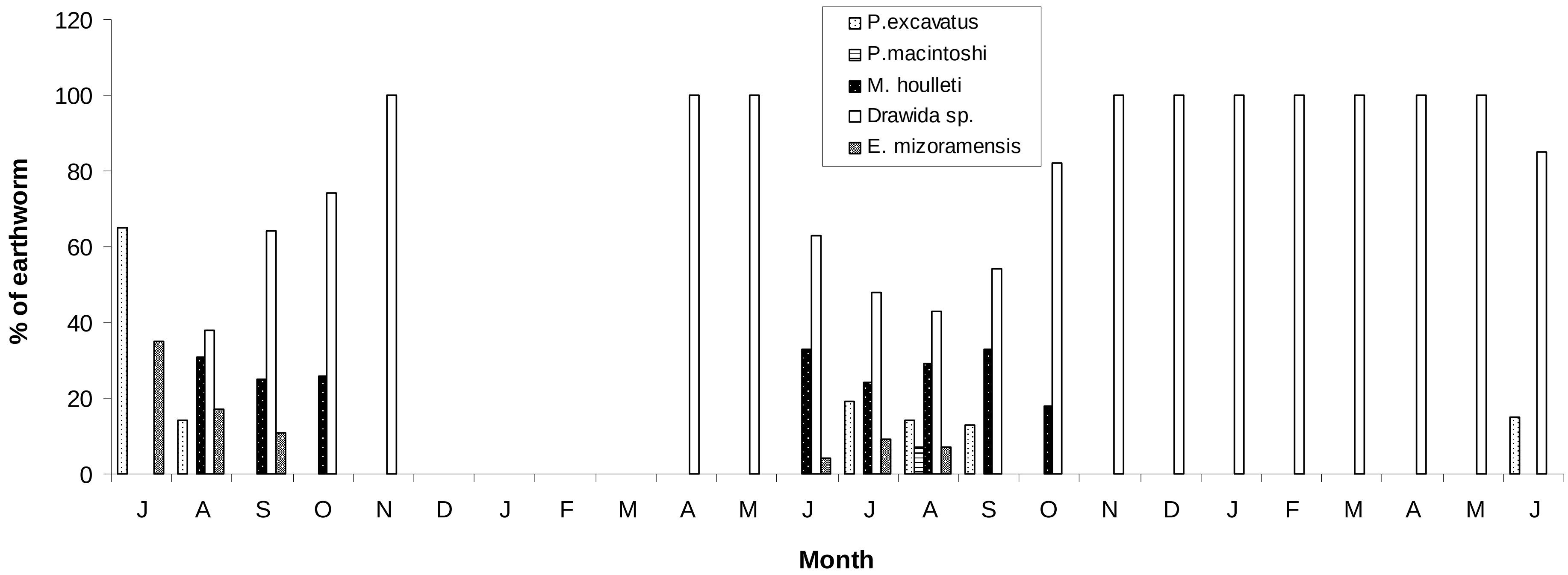
Table 49: ANOVA of earthworm species-wise effect of NPK treatment in ML agroforestry sites

Earthworm species	SKT	PUC
	F-ratio	F-ratio
Perionyx excavatus	0	0.028 ^{NS}
Metaphire houletti	5.390 ^{NS}	0
Drawida sp.	0	26.570 ^{NS}
Eutyphoeus mizoramensis	2.782 ^{NS}	0
Perionyx macintoshi	**NA**	0

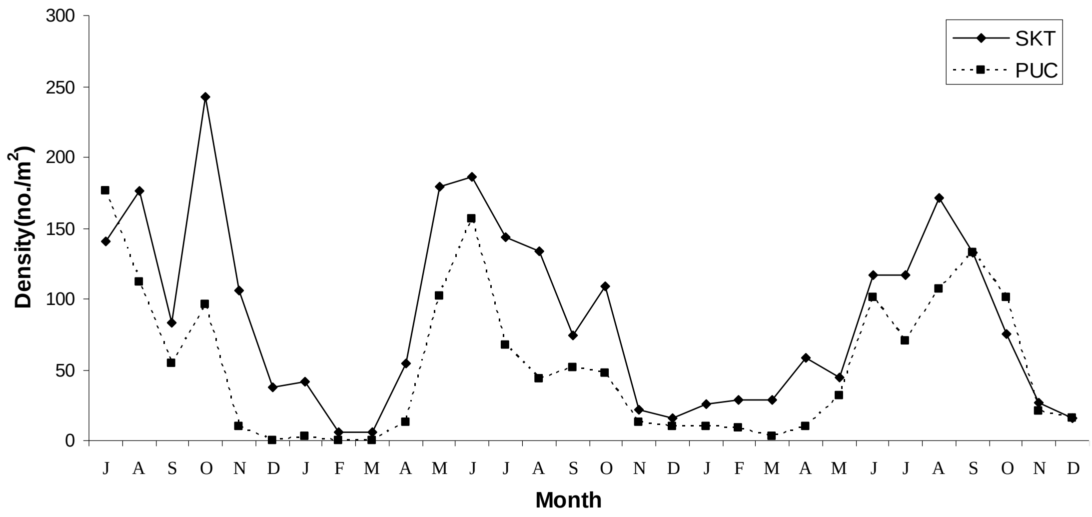
Level of significance *P<0.05 **P<0.01, NS = Not significant



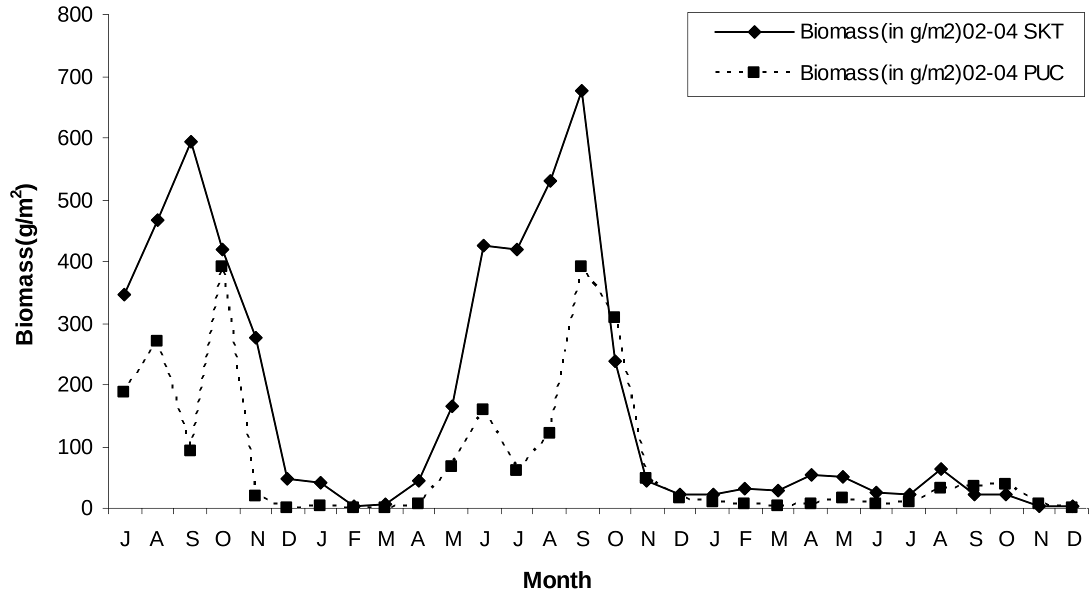
Graph 1: Monthly distribution of different species of earthworms (%) in SKT agroforestry site (July 2002 – June 2004)



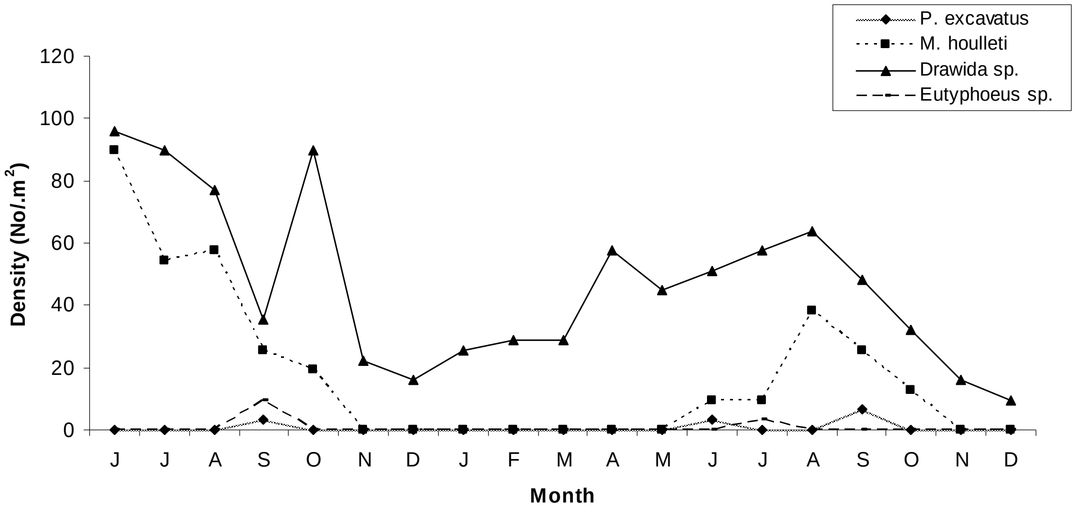
Graph 2: Monthly distribution of different species of earthworms (%) in PUC agroforestry site (July 2002 – June 2004)



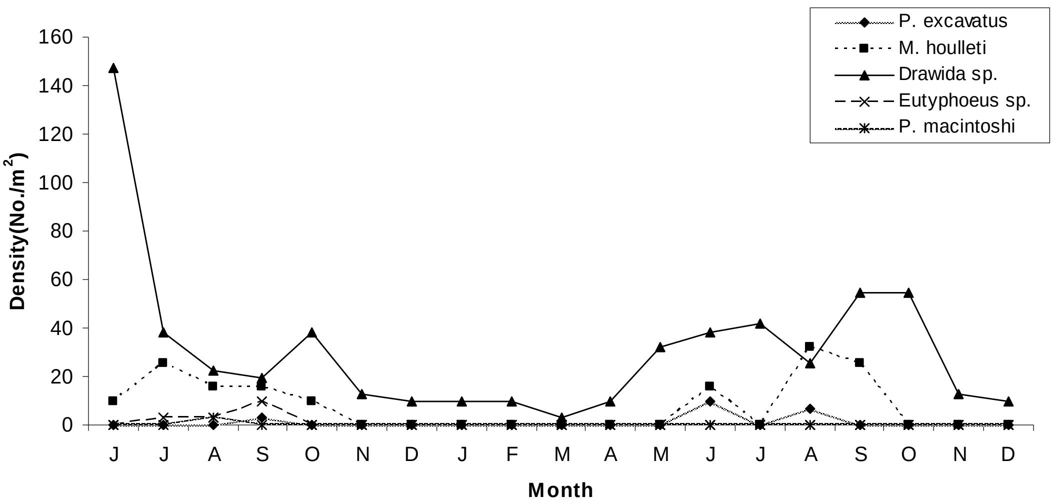
Graph 3: Comparison of earthworm density (no/m^2) in the two agroforestry experimental sites (July 2002 - December 2004)



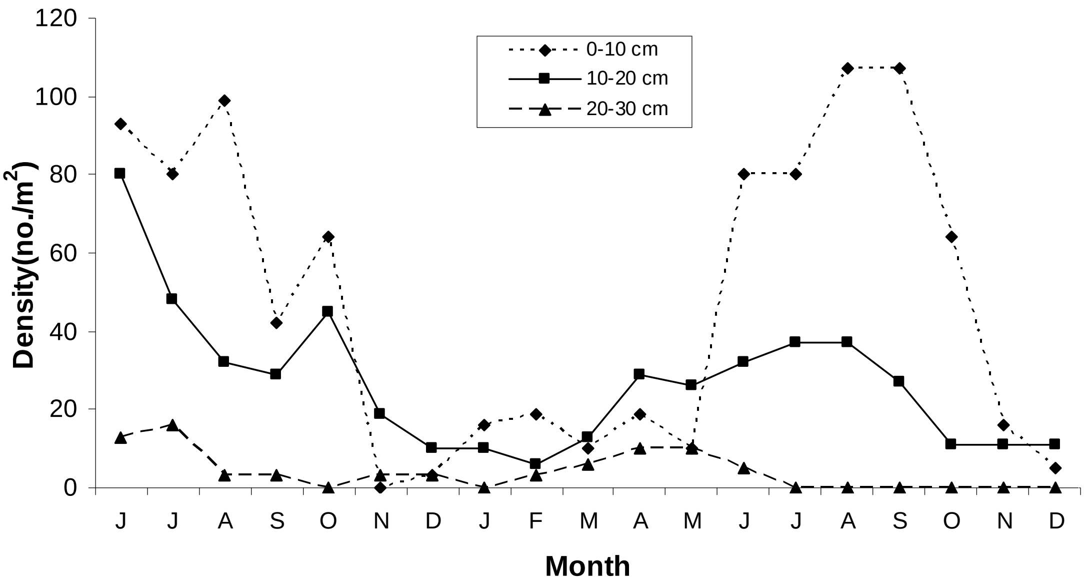
Graph 4: Comparison of earthworm biomass (g/m^2) in the two agroforestry experimental sites (July 2002 – December 2004)



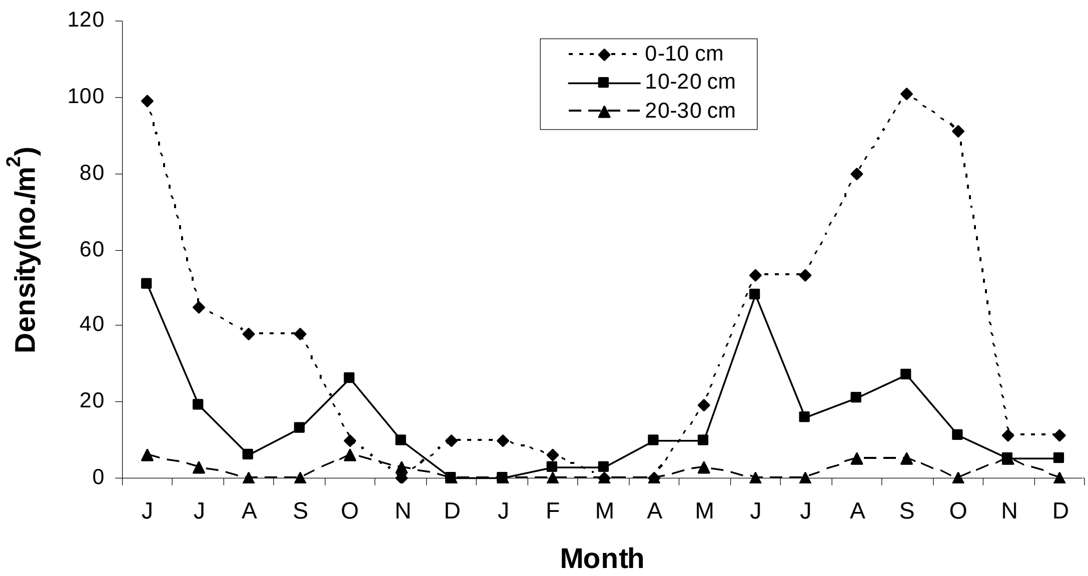
Graph 5: Density (no/m^2) of earthworm (species wise) in SKT agroforestry experimental site (June 2003 - December 2004)



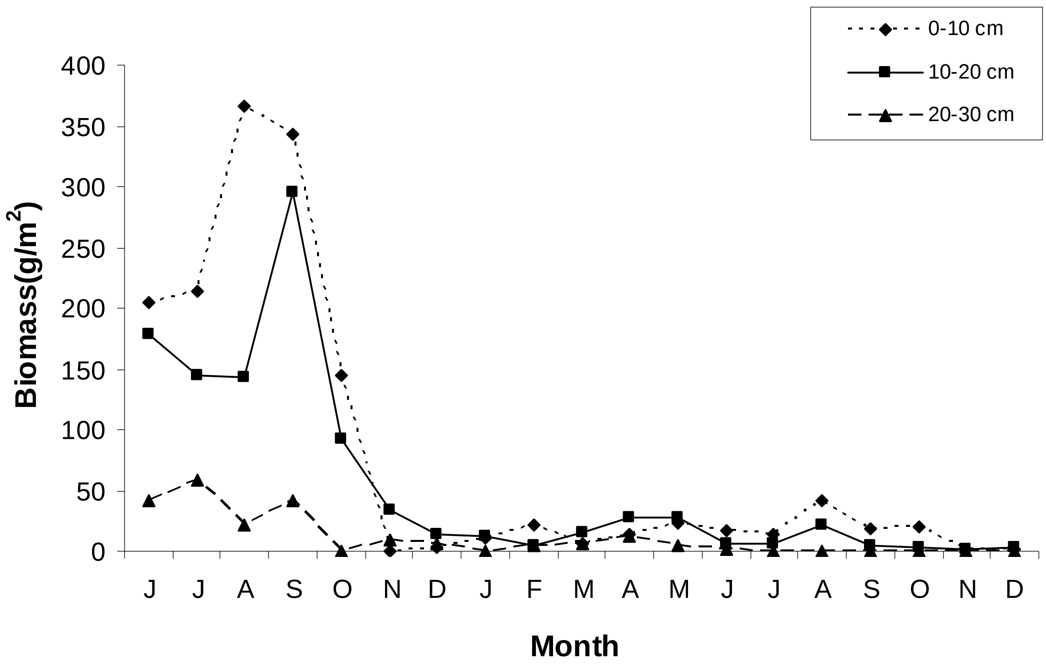
Graph 6: Density (no/m^2) of earthworm (species wise) in PUC agroforestry experimental site (June 2003 - December 2004)



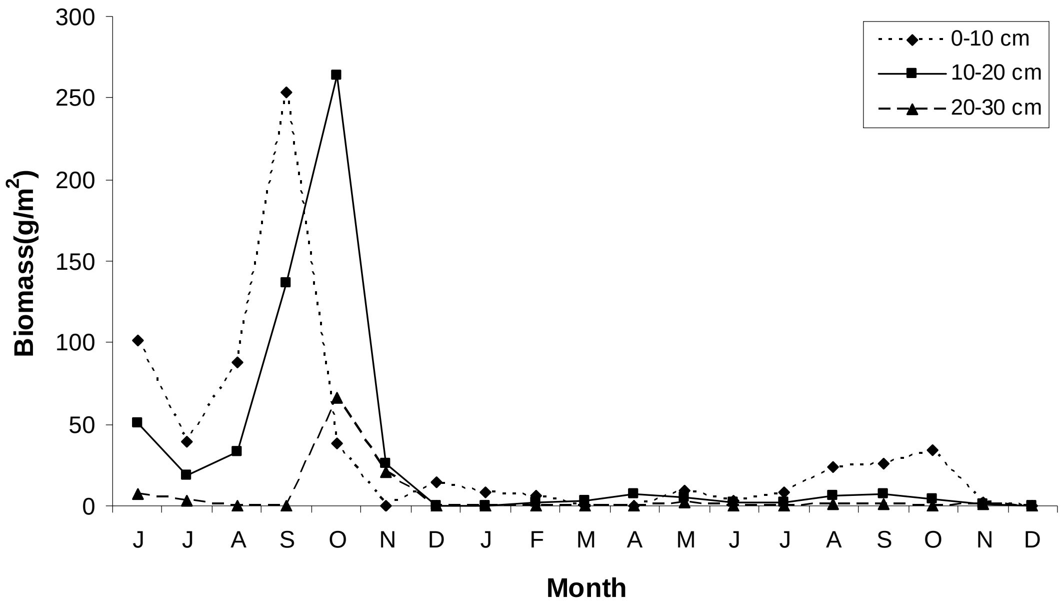
Graph 7: Density (no/m²) of earthworm (strata-wise) in SKT agroforestry experimental site (June 2003 – December 2004)



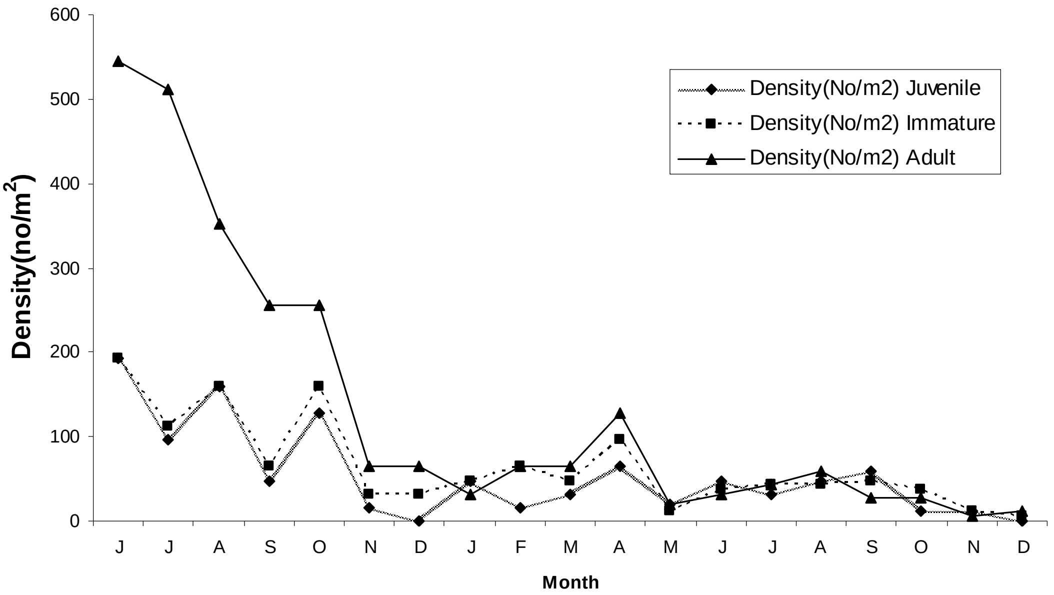
Graph 8: Density (no/m²) of earthworm (strata-wise) in PUC agroforestry experimental site (June 2003 – December 2004)



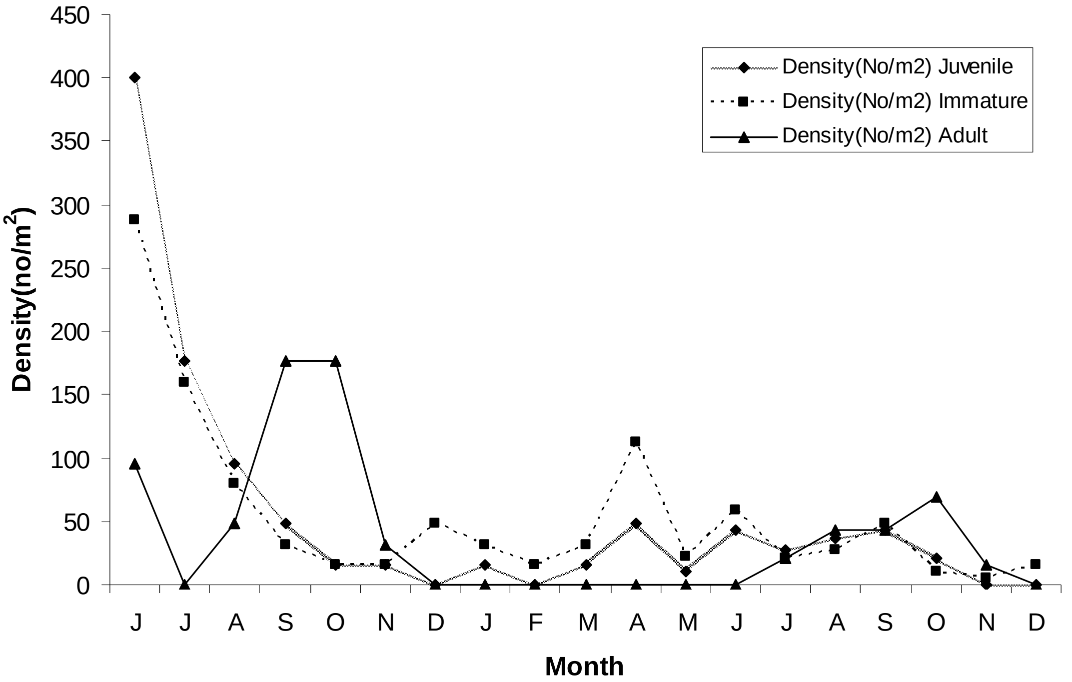
Graph 9: Biomass (g/m^2) of earthworm (strata-wise) in SKT agroforestry experimental site (June 2003 – December 2004)



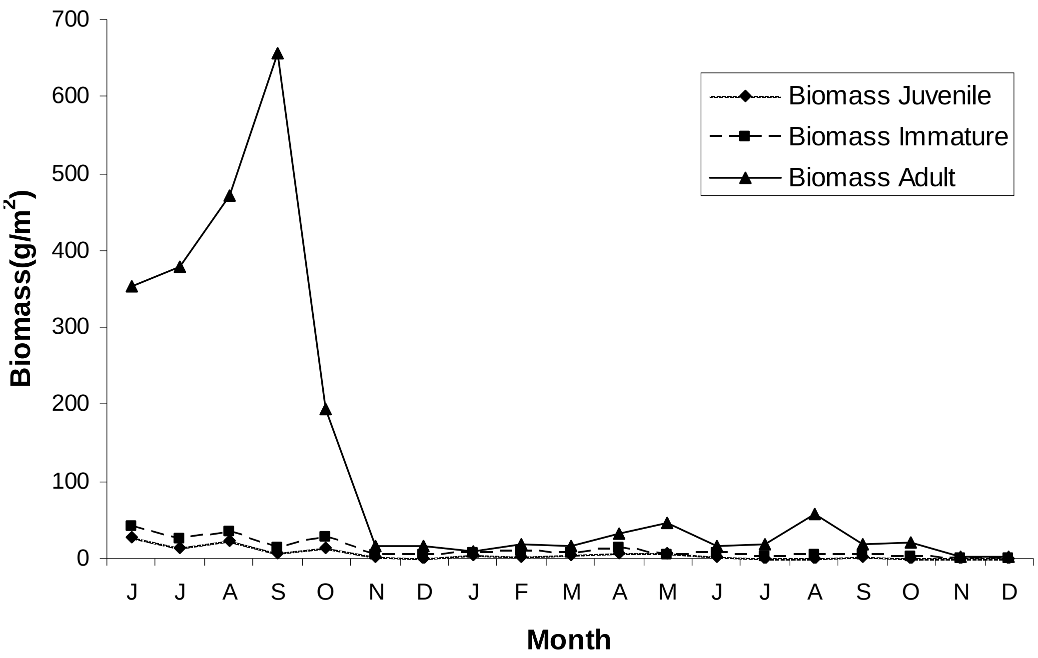
Graph 10: Biomass (g/m^2) of earthworm (strata-wise) in PUC agroforestry experimental site (June 2003 – December 2004)



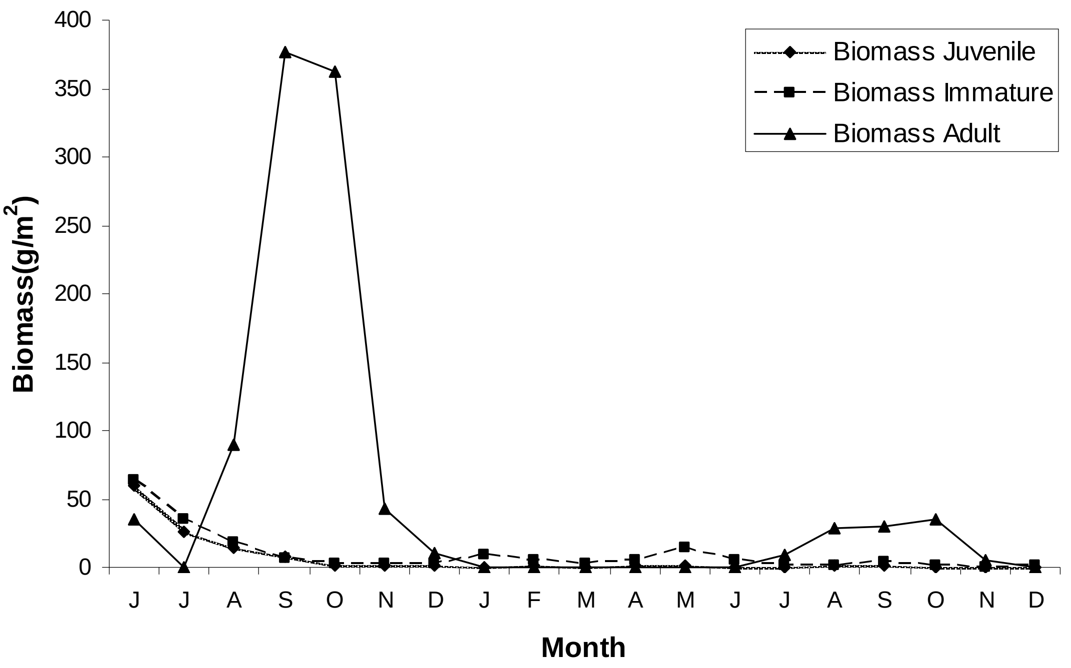
Graph 11: Density (no/m^2) of earthworm (age-wise) in SKT agroforestry experimental sites (June 2003 - December 2004)



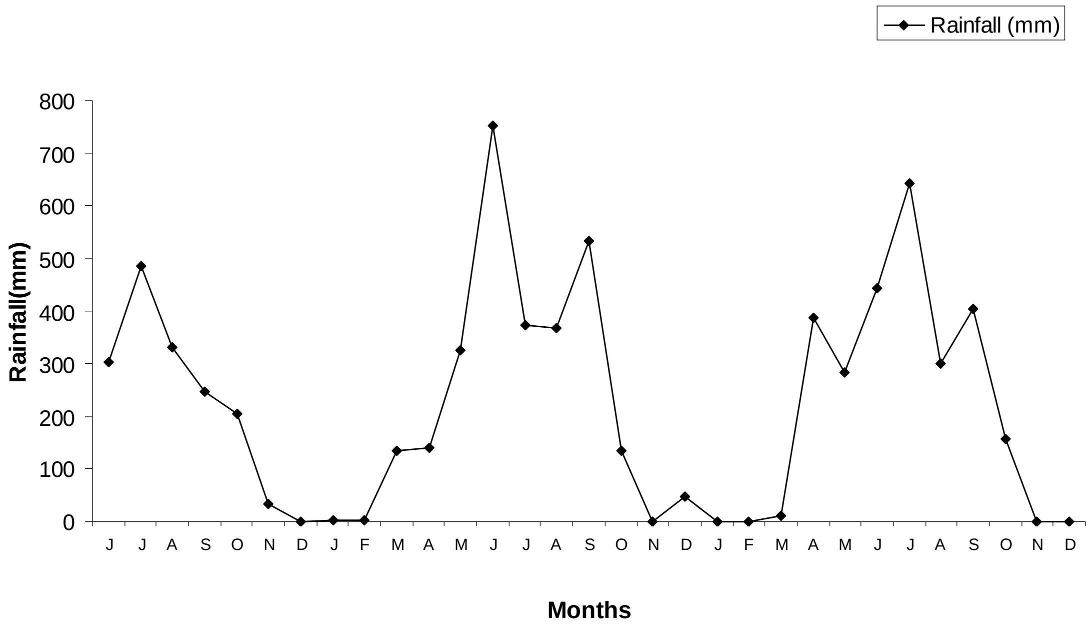
Graph 12: Density (no/m^2) of earthworm (age-wise) in PUC agroforestry experimental sites (June 2003 - December 2004)



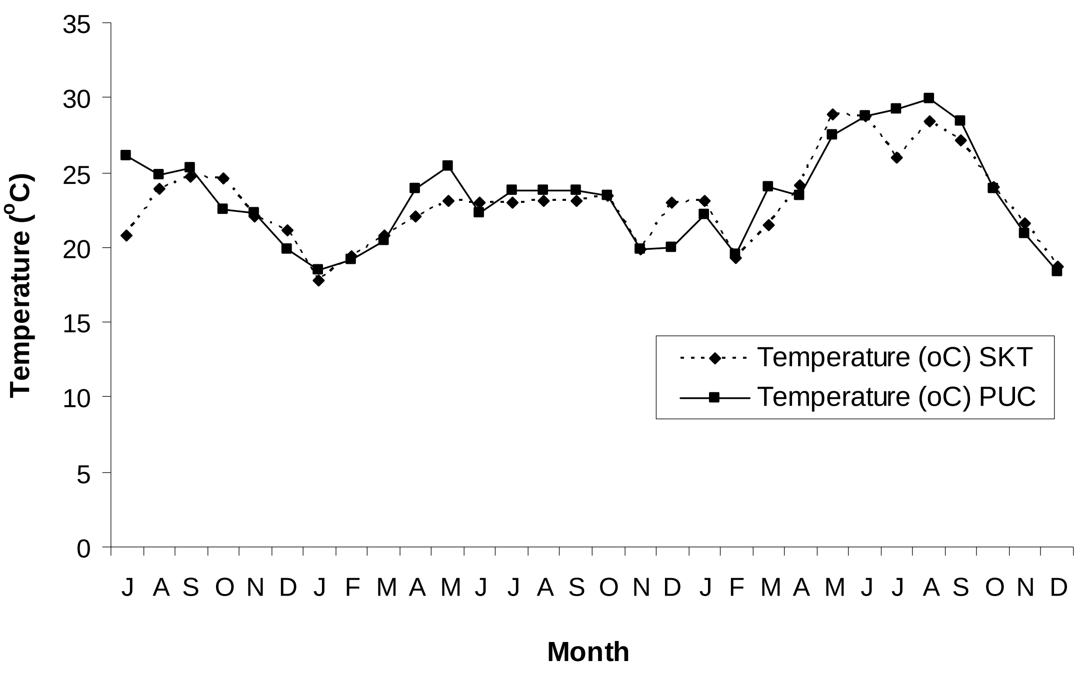
Graph 13: Biomass (g/m^2) of earthworm (age-wise) in SKT agroforestry experimental sites (June 2003 - December 2004)



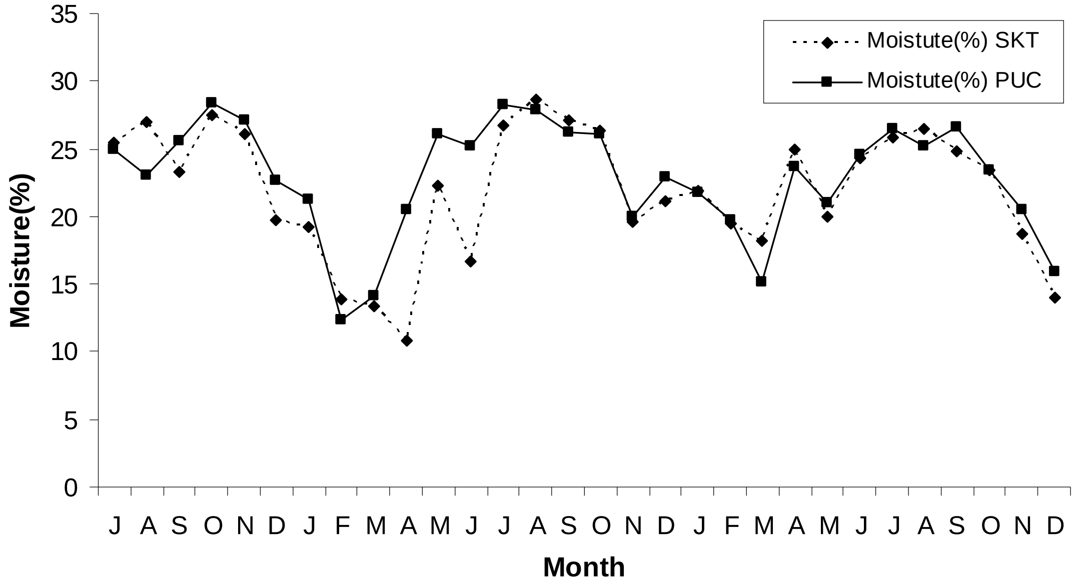
Graph 14: Biomass (g/m^2) of earthworm (age-wise) PUC agroforestry experimental sites (June 2003 - December 2004)



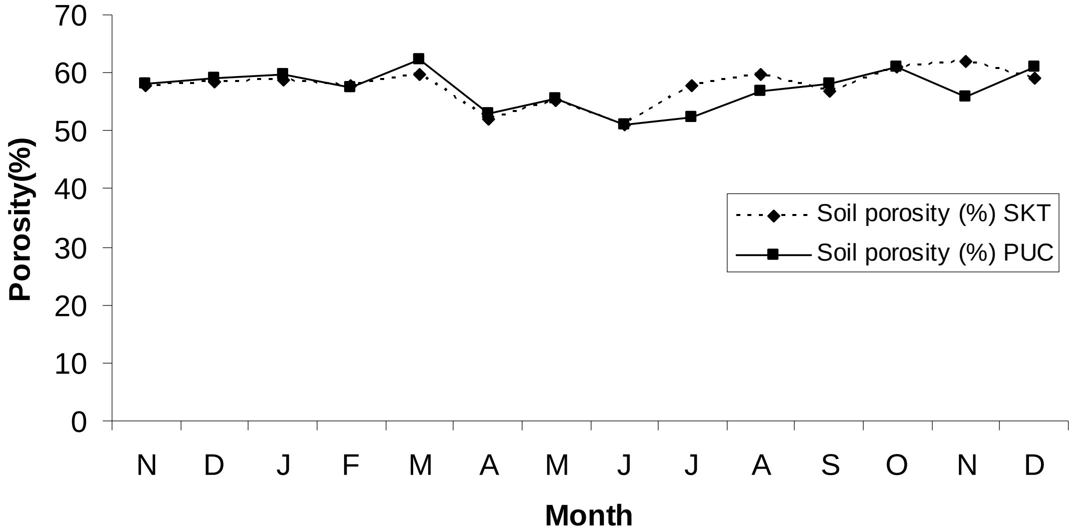
Graph 15: Monthly variation in rainfall (mm) (June 2002 – December 2004)



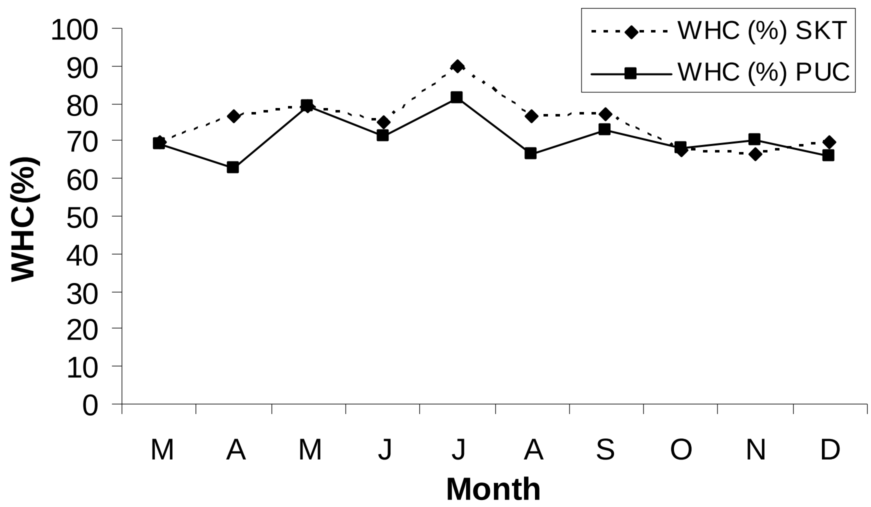
Graph 16: Monthly variation in soil temperature (°C) of the two agroforestry experimental sites (July 2002 – December 2004)



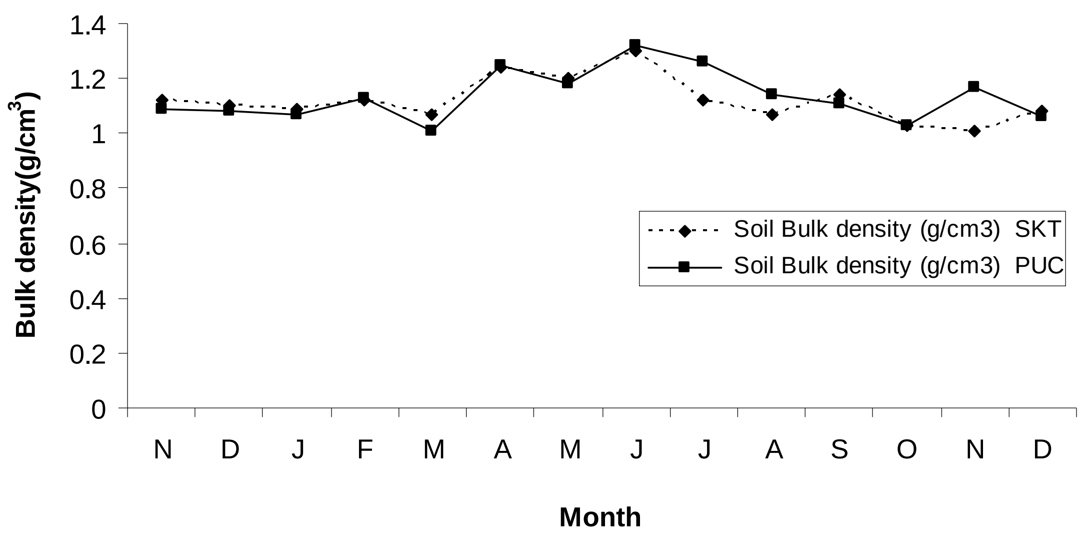
Graph 17: Monthly variation in soil moisture content (%) of the two agroforestry experimental sites (July 2002 – December 2004)



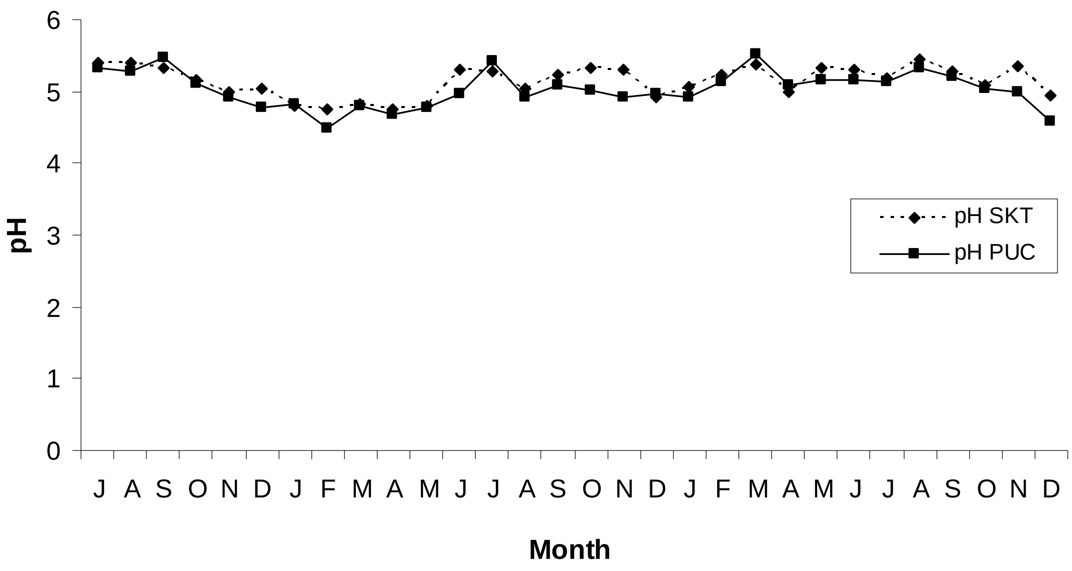
Graph 18: Monthly variation in soil porosity (%) of the two agroforestry experimental sites (November 2003 – December 2004)



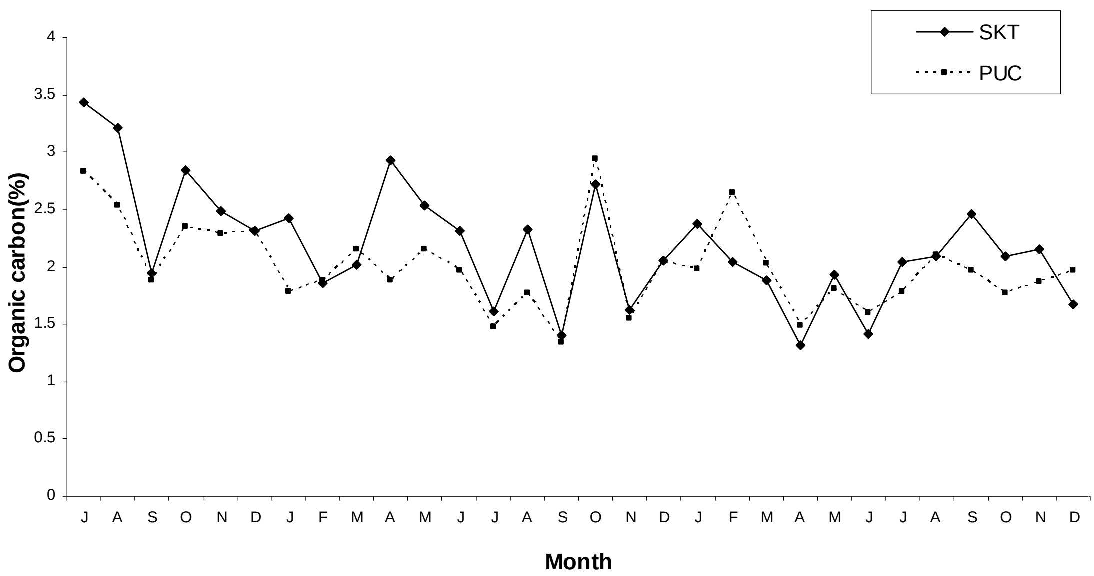
Graph 19: Monthly variation in WHC (%) of the two agroforestry experimental sites (March – December 2004)



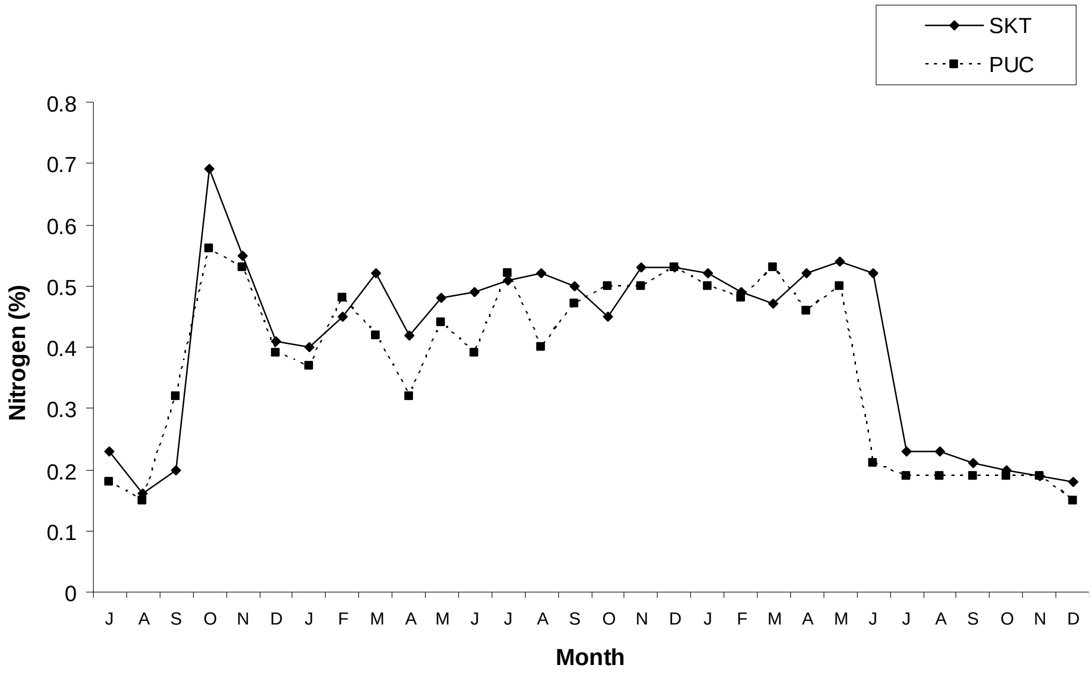
Graph 20: Monthly variation in soil bulk density (g/cm^3) of the agroforestry experimental sites (November 2003 – December 2004)



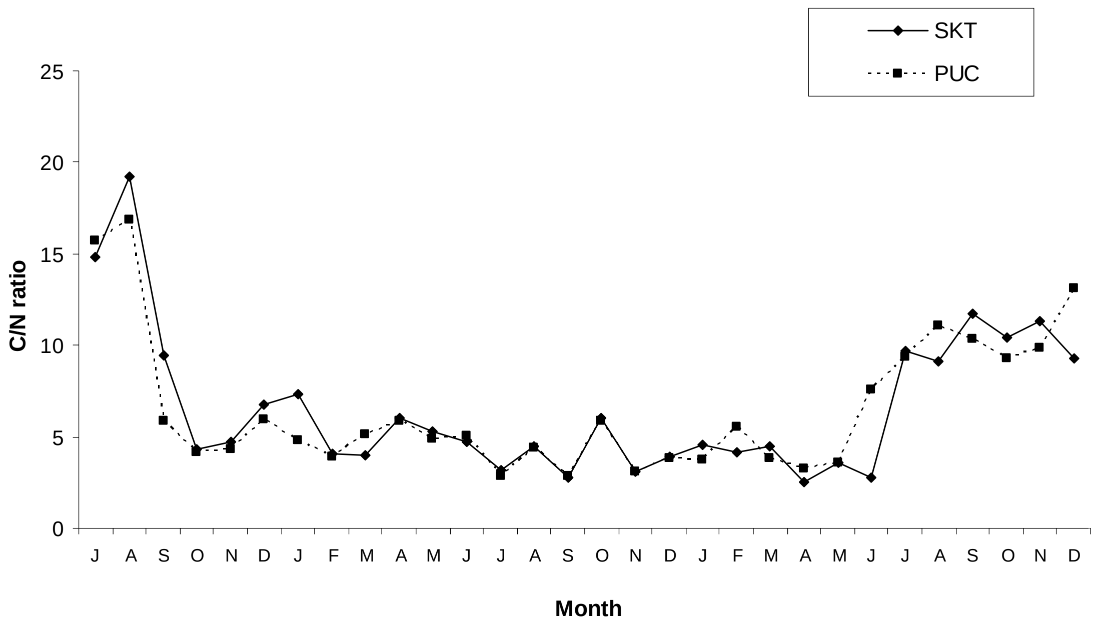
Graph 21: Monthly variation in soil pH of the two agroforestry experimental sites (July 2002 – December 2004)



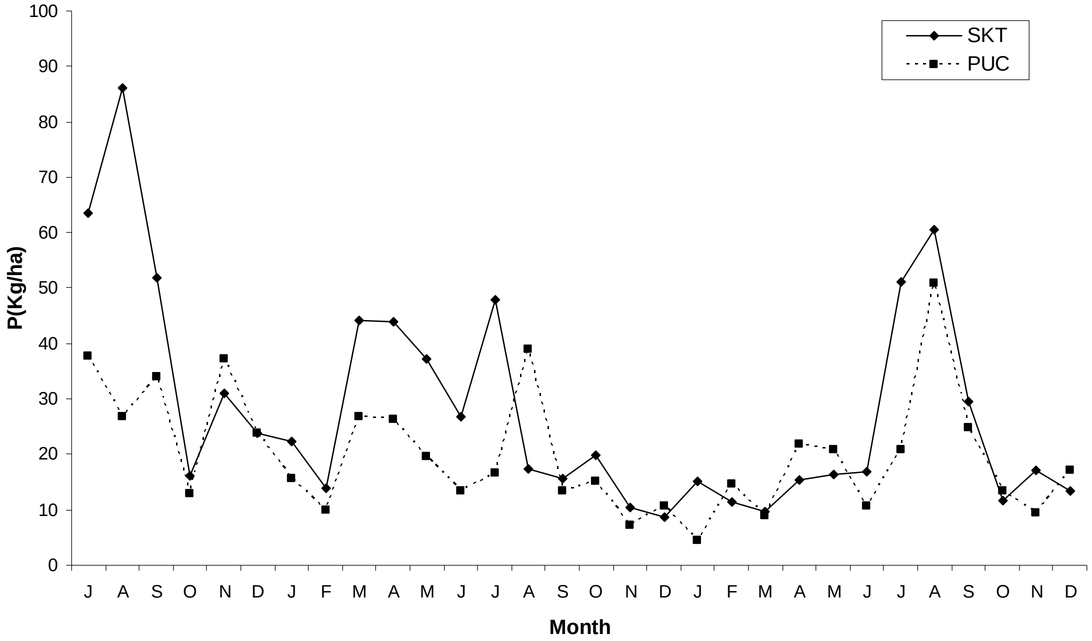
Graph 22: Monthly variation in soil organic carbon (%) of the two agroforestry experimental sites (July 2002 – December 2004)



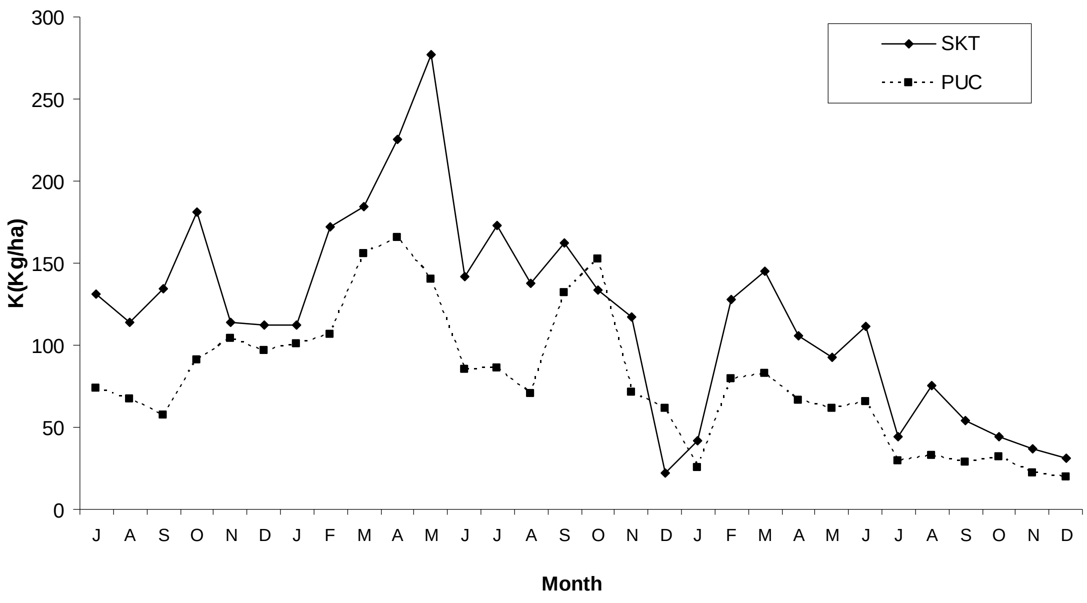
Graph 23: Monthly variation in soil nitrogen (%) content of the two agroforestry experimental sites (July 2002 – December 2004)



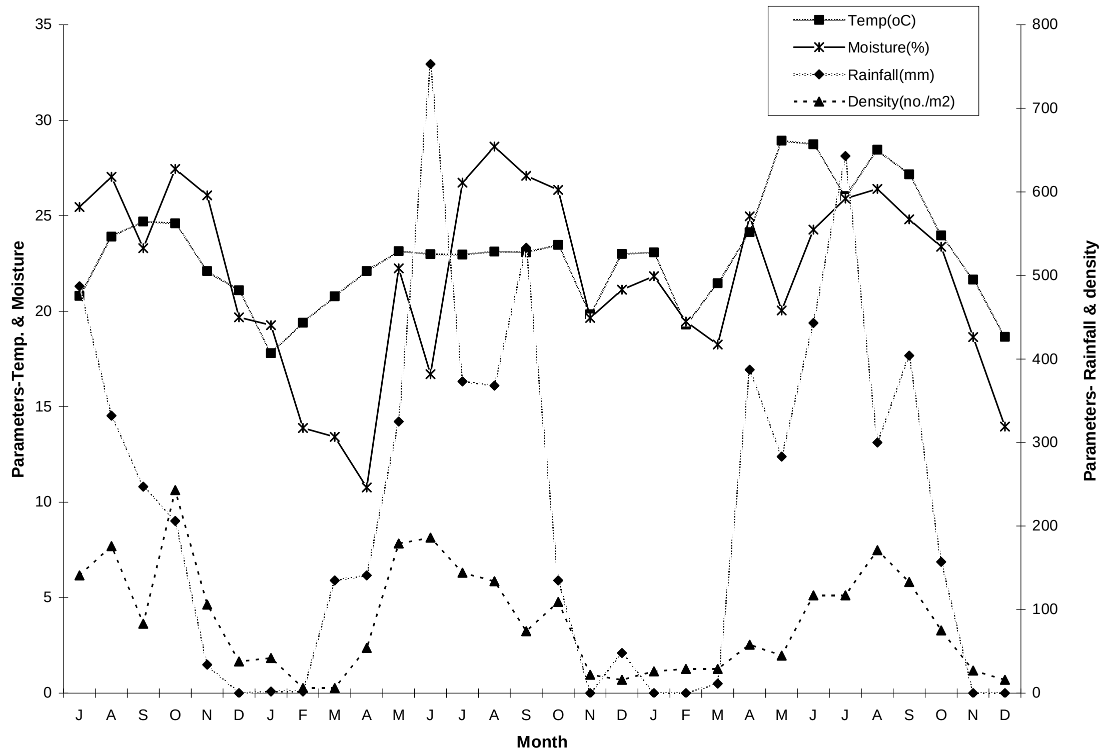
Graph 24: Monthly variation in soil C/N ratio of the two agroforestry experimental sites (July 2002 – December 2004)



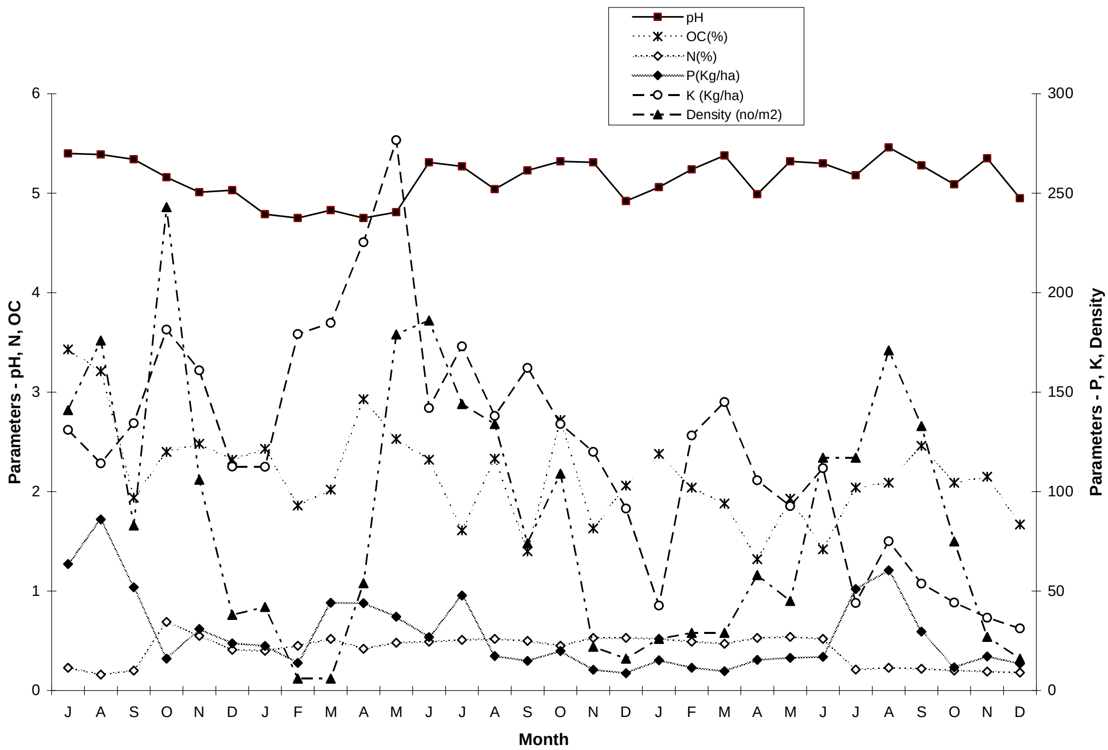
Graph 25: Monthly variation in soil available phosphorus (Kg/ha) of the agroforestry experimental sites (July 2002 – December 2004)



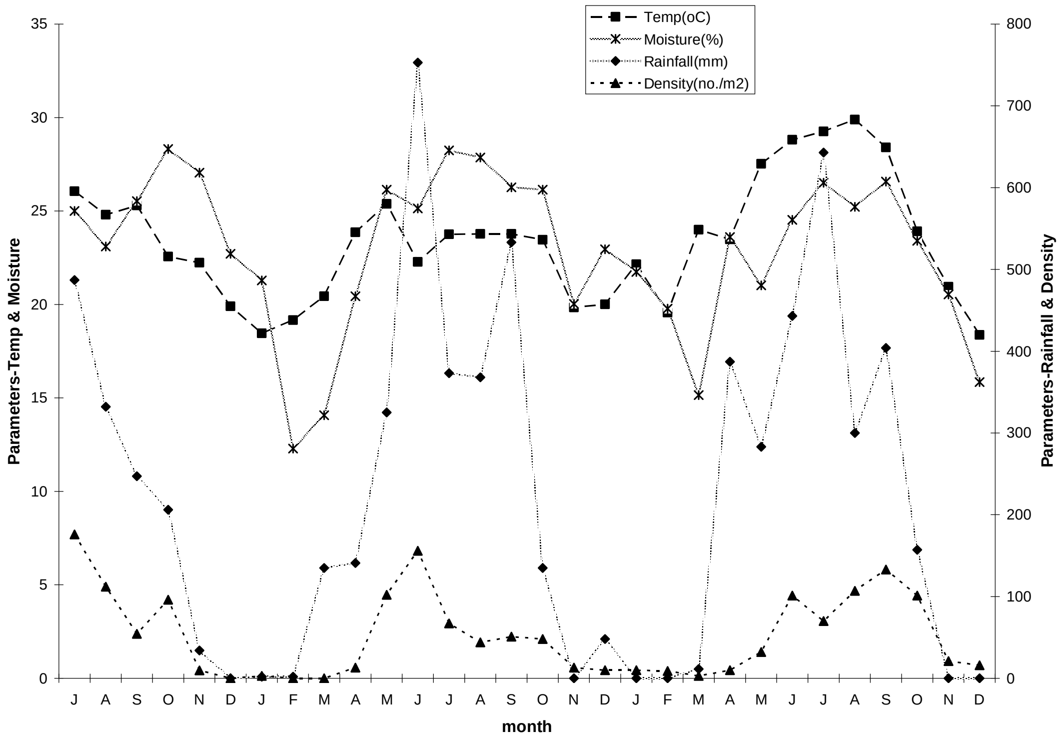
Graph 26: Monthly variation in soil available potassium (Kg/ha) of the agroforestry experimental sites (July 2002 – December 2004)



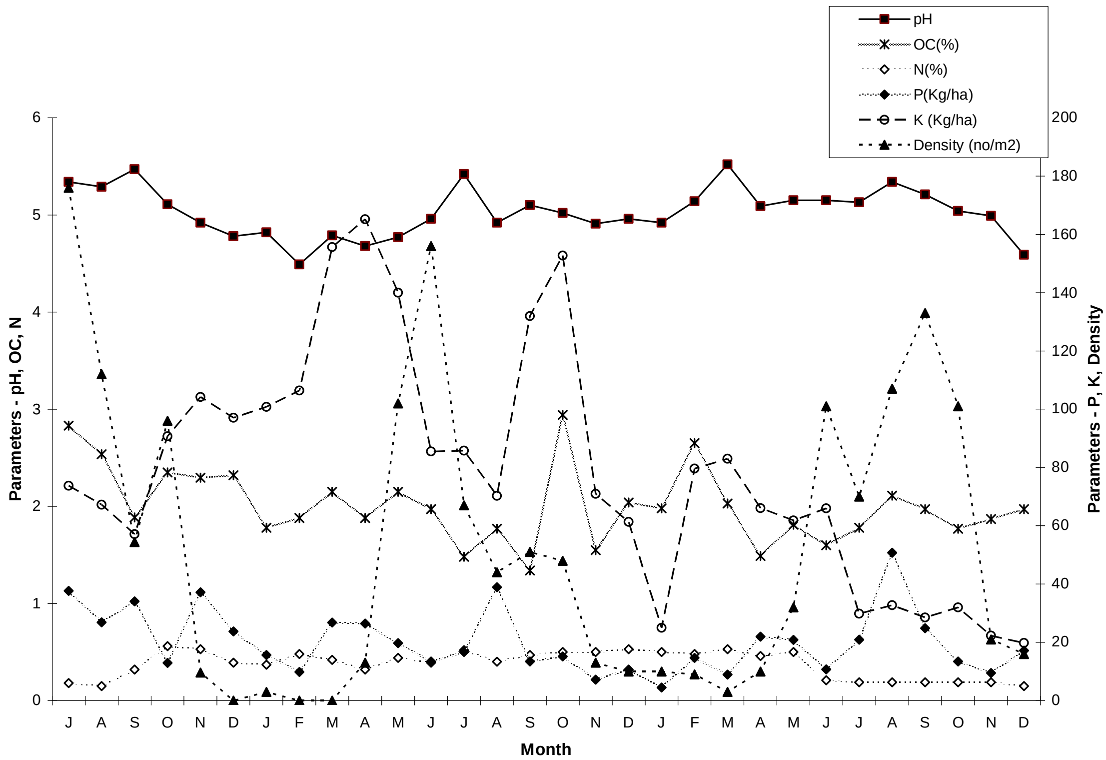
Graph 27: Comparison of monthly variation in climatic factors with population density (no/m²) in SKT agroforestry experimental site



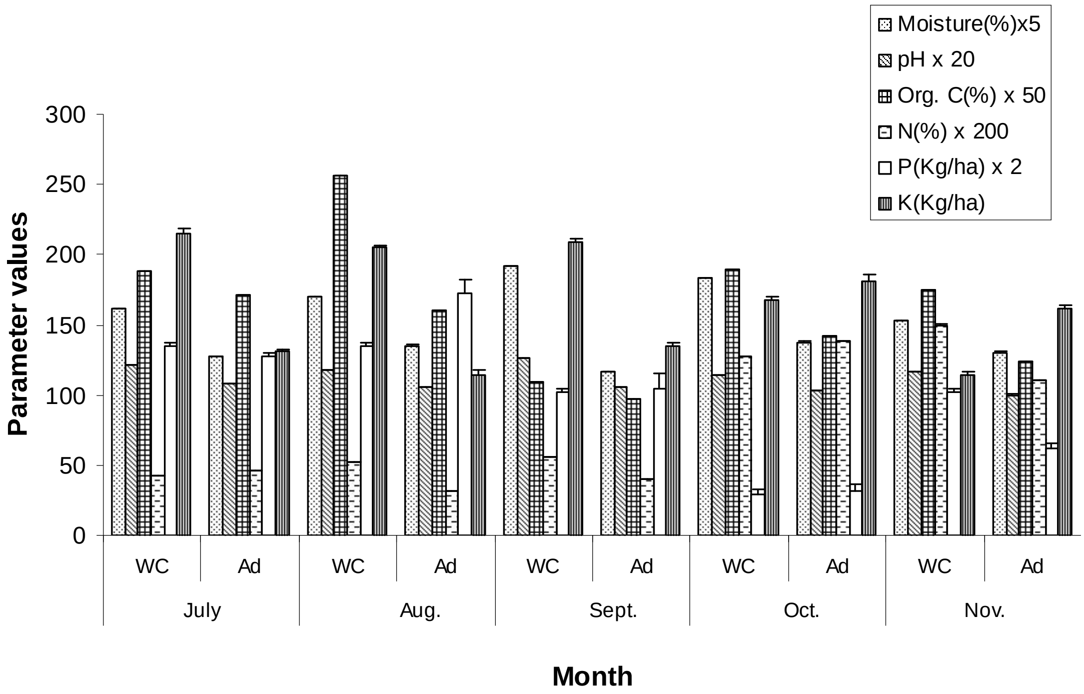
Graph 28: Comparison of monthly variation in chemical component with population density (no/m²) in SKT agroforestry experimental site



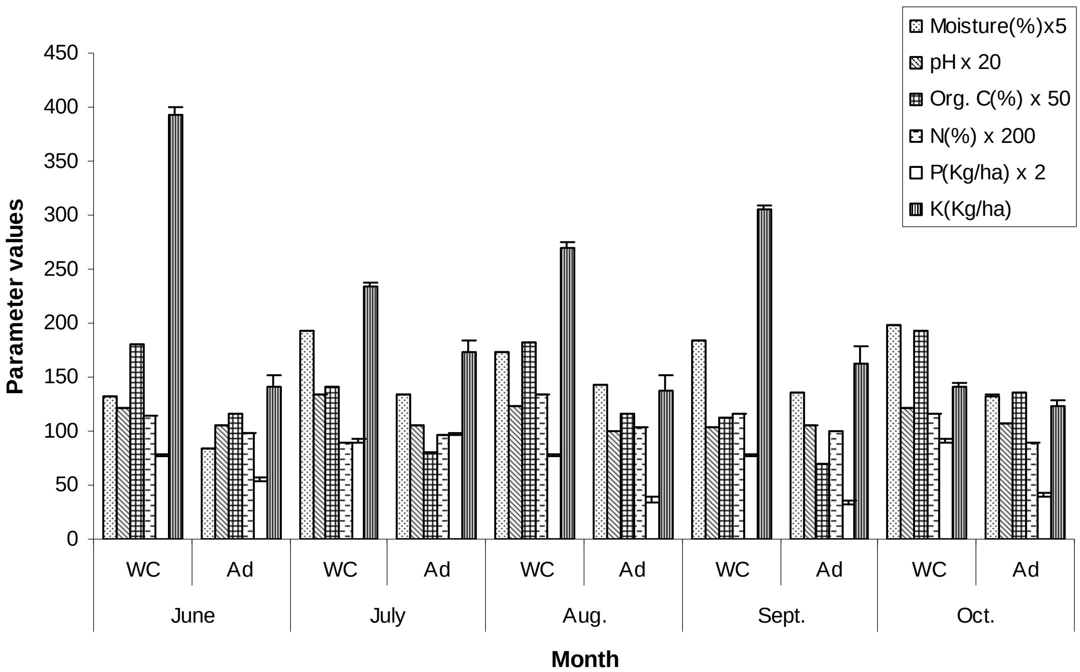
Graph 29: Comparison of seasonal variation in physical factors with population density (no/m^2) in PUC agroforestry experimental site



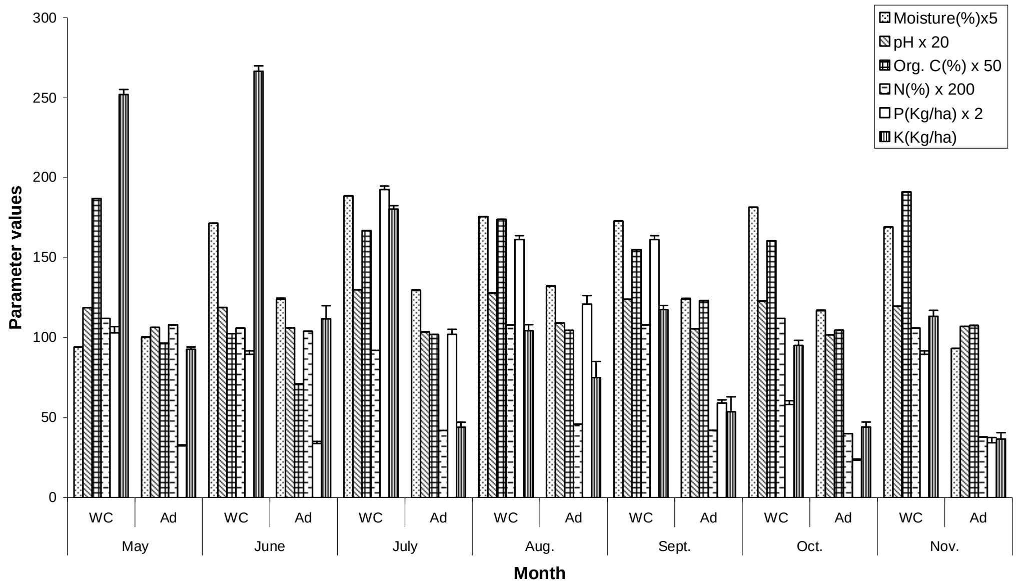
Graph 30: Comparison of seasonal variation in chemical component with population density (no/m^2) in PUC agroforestry experimental site



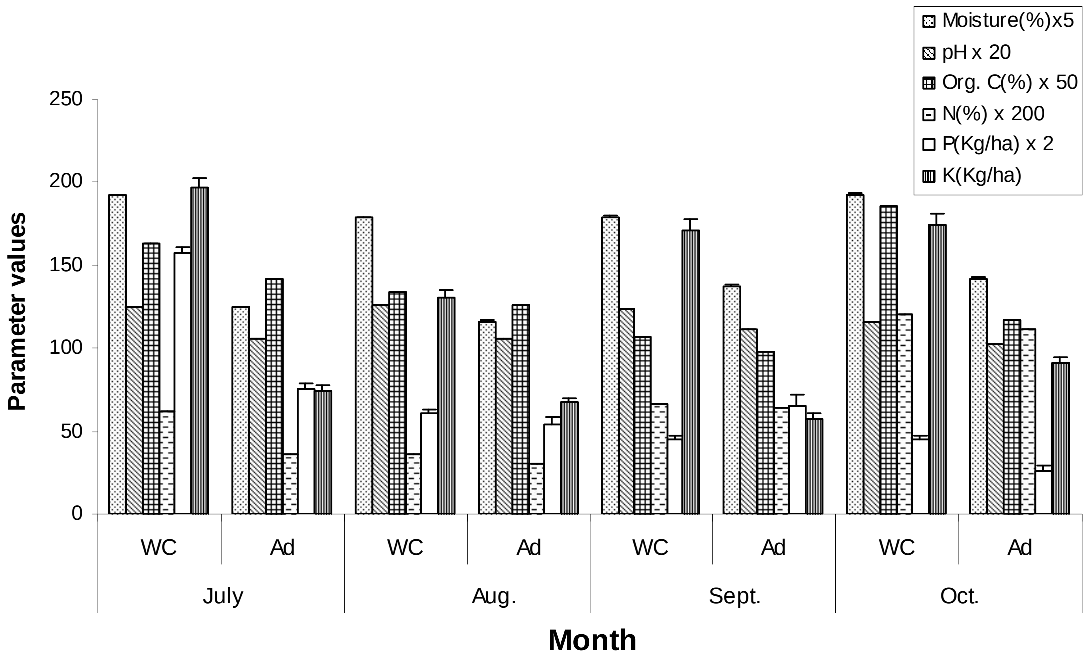
Graph 31: Physico-chemical comparison of worm cast with adjacent soil in SKT agroforestry experimental site (2002)



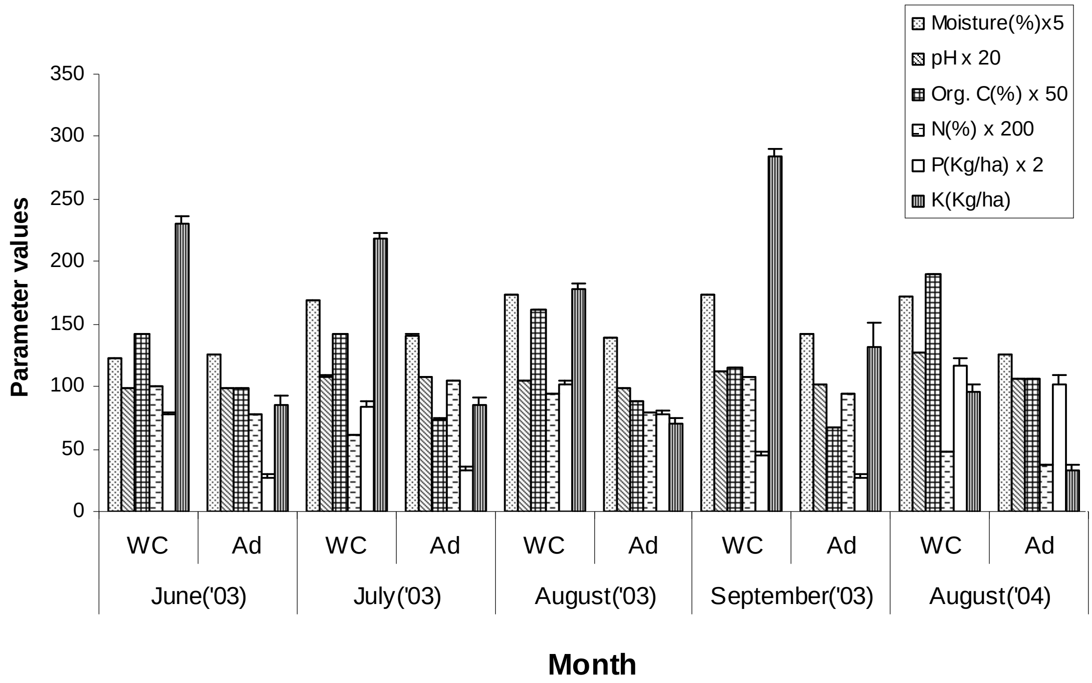
Graph 32: Physico-chemical comparison of worm cast with adjacent soil in SKT agroforestry experimental site (2003)



Graph 33: Physico-chemical comparison of worm cast with adjacent soil in SKT agroforestry experimental site (2004)

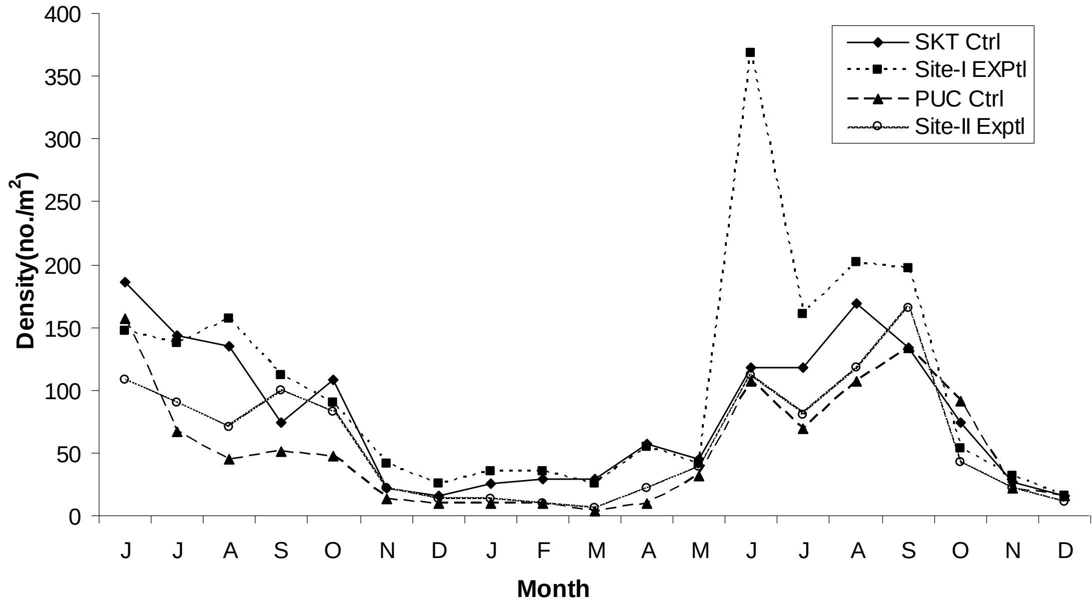


Graph 34: Physico-chemical comparison of worm cast with adjacent soil in PUC agroforestry experimental site (2002)

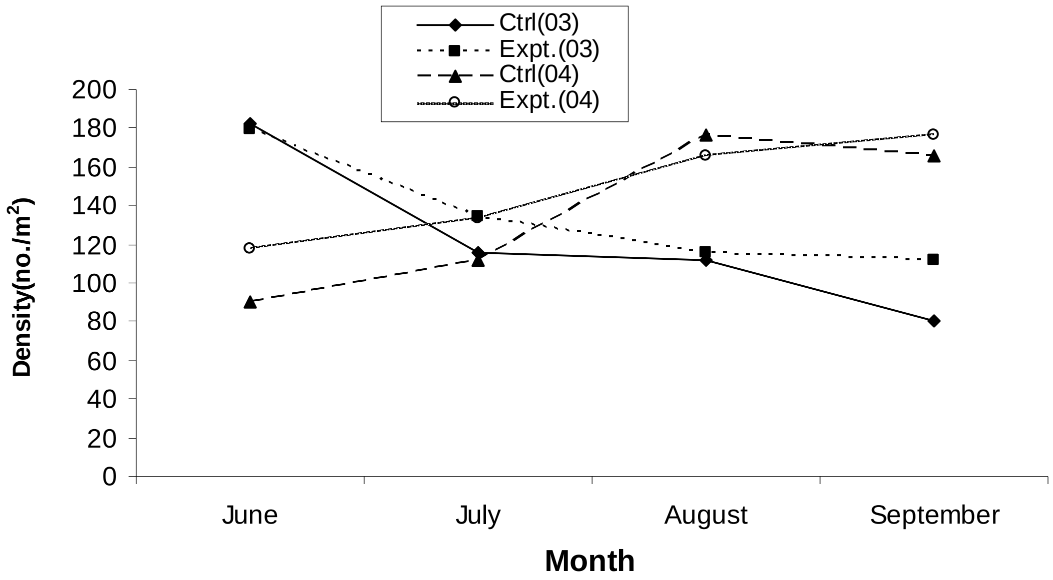


Graph 35: Physico-chemical comparison of worm cast with adjacent soil in PUC agroforestry experimental site (2003 - 2004)

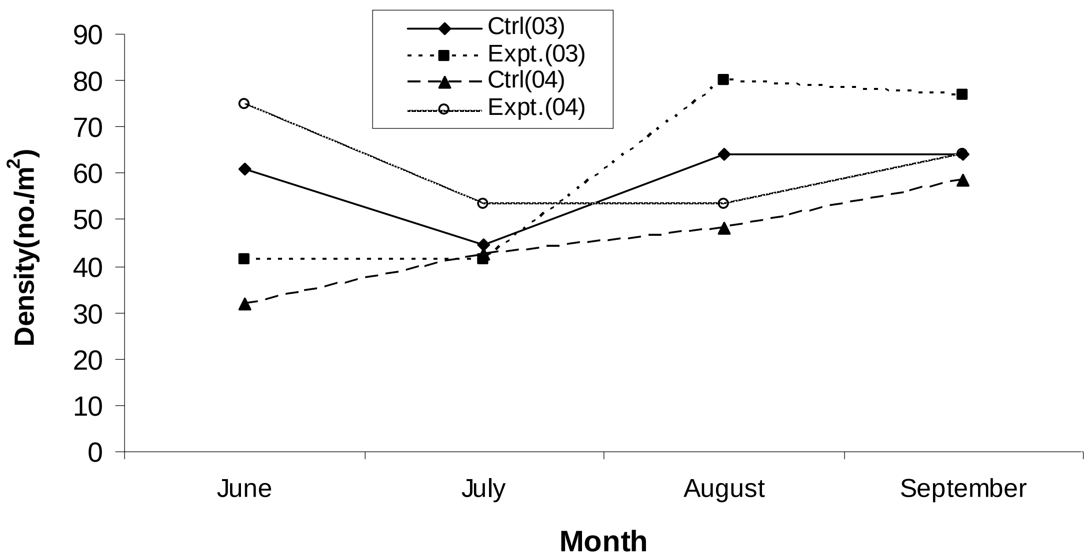
***WC,** Worm cast; **Ad**, adjacent soil.*



Graph 36: Effect of NPK on earthworm density (no/m^2) in PCL agroforestry system of SKT and PUC experimental sites



Graph 37: Effect of NPK on earthworm density (no/m^2) in ML agroforestry system of SKT experimental site



Graph 38: Effect of NPK on earthworm density (no/m^2) in ML agroforestry system in PUC experimental site

Figure 1: Geographical location of Mizoram

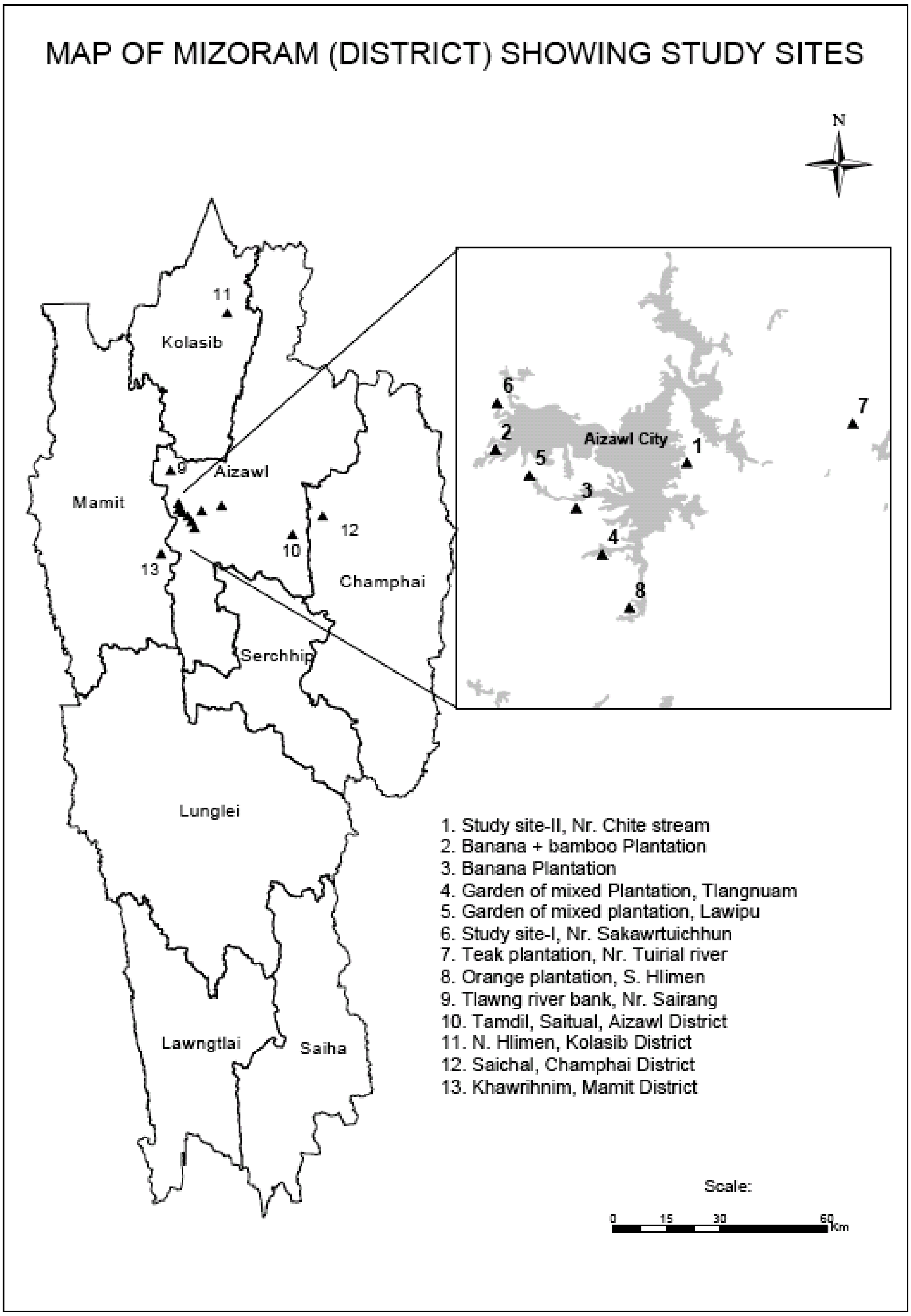


Figure 2: Map of Mizoram showing study sites

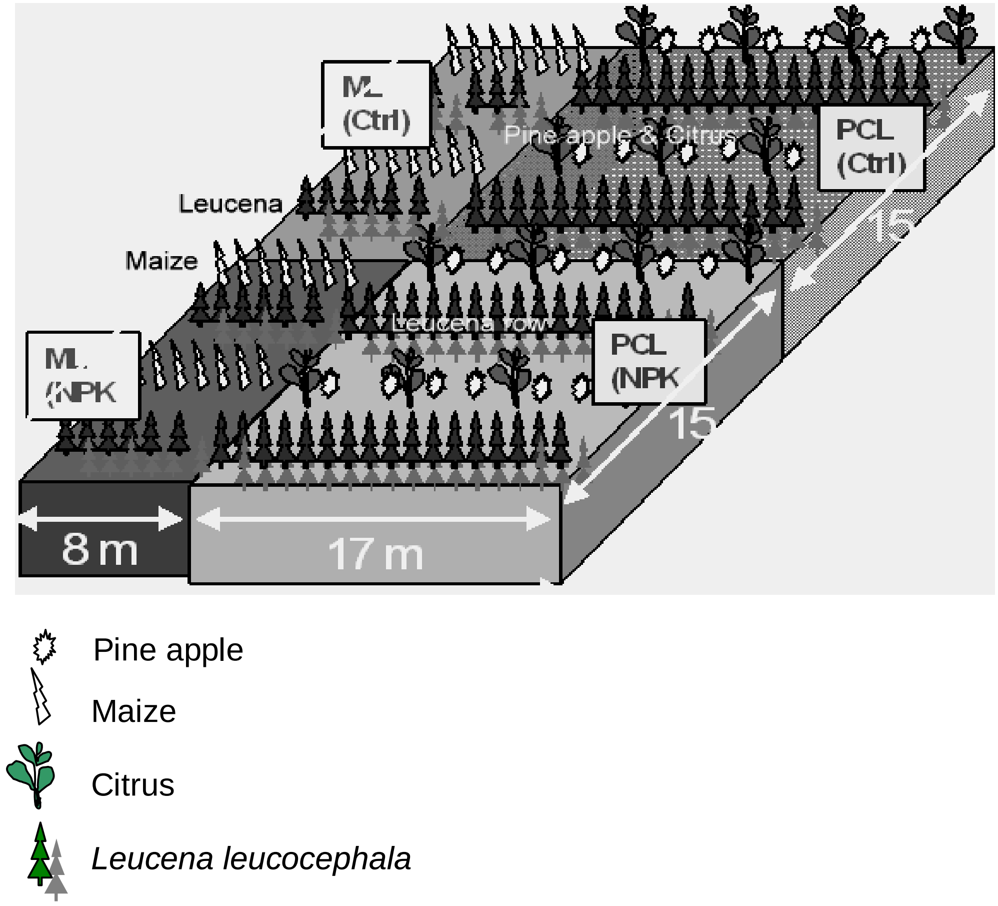


Figure 3: Design of experimental plots

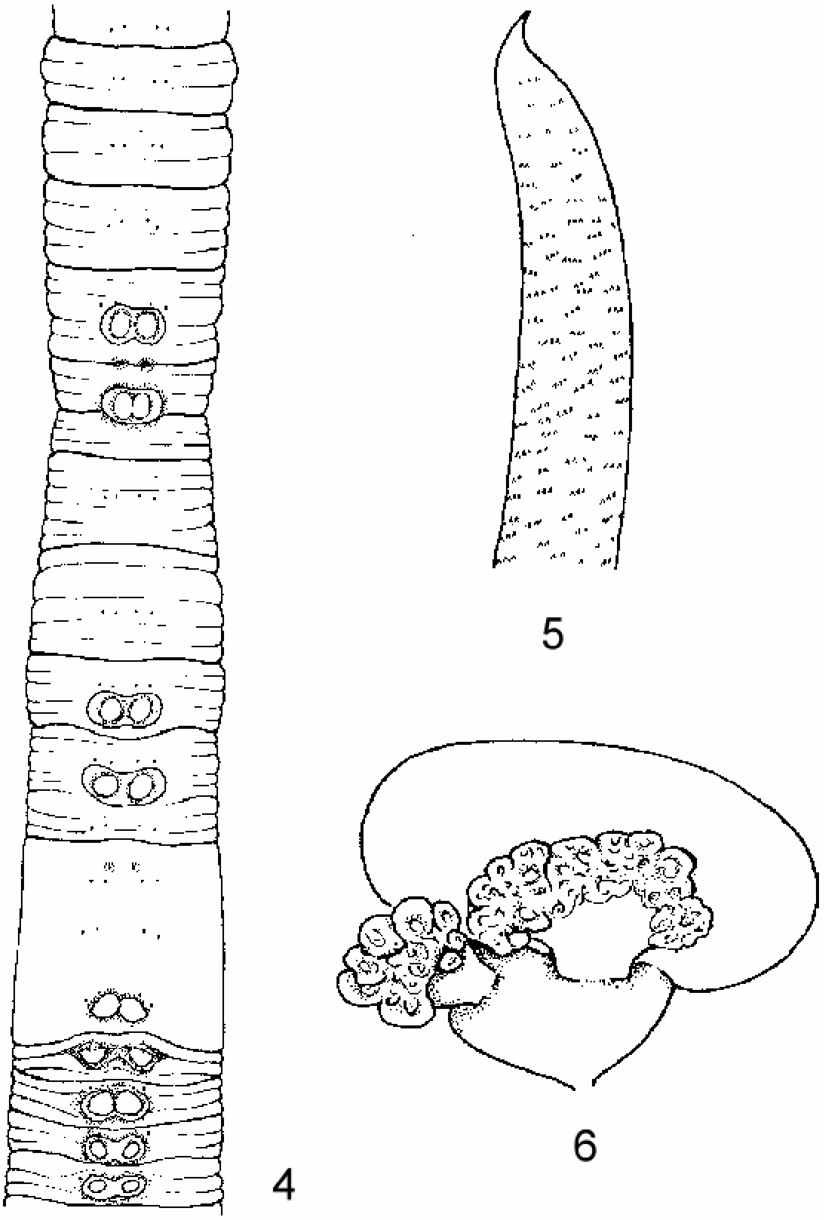


Figure 4 – 6: ***Eutyphoeus mizoramensis*** **sp. nov.**

4. Genital region

5. Penial seta

6. Spermatheca

1. a) PCL plantations

1. b) Pine apple with *Leucaena leucocephala*

1. c) Maize plantation

Photo plate 1 : Experimental site SKT (first year)

2. a) Pine apple and Citrus

2. b) Pine apple with *Leucaena leucocephala*

2. c) Maize plantation

Photo plate 2 : Experimental site PUC (first year)

3. a) Teak plantation

3. b) Orange plantation

3. c) Banana + Bamboo plantation

3. d) Banana plantation

3. e) Tlawng river bank

3. f) Paddy field

Photo plate 3 : Some other study sites

4. a) *Perionyx excavatus*

4. b) *Perionyx macintoshi*

4. c) *Metaphire houletti*

Photo plate 4 : Earthworms


5. a) *Amynthas alexandri*


5. b) *Amynthas cortices*


5. c) *Eutyphoeus assammensis*

Photo plate 5 : Earthworms

6. a) *Eutyphoeus mizoramensis sp. nov.* - Ventral view

6. b) *Eutyphoeus mizoramensis sp. nov.* - Dorsal view

6. c) *Eutyphoeus gigas*

Photo plate 6 : Earthworms

7. a) *Drawida sp.*

7. b) *Drawida nepalensis*

7. c) *Drawida rangamatiana*

Photo plate 7 : Earthworms

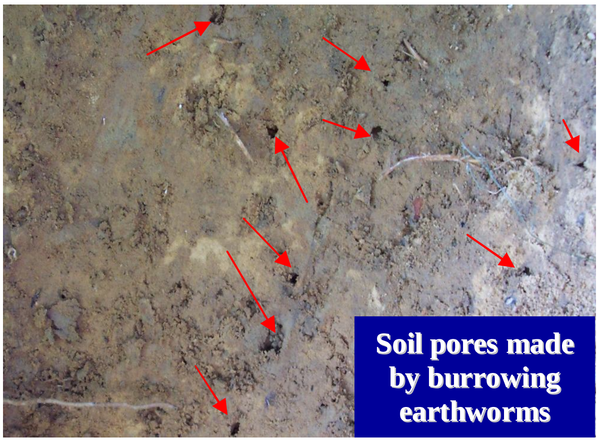
8. *a) Drawida nagana*

8. b) Worm cast of *Eutyphoeus mizoramensis* sp. nov.

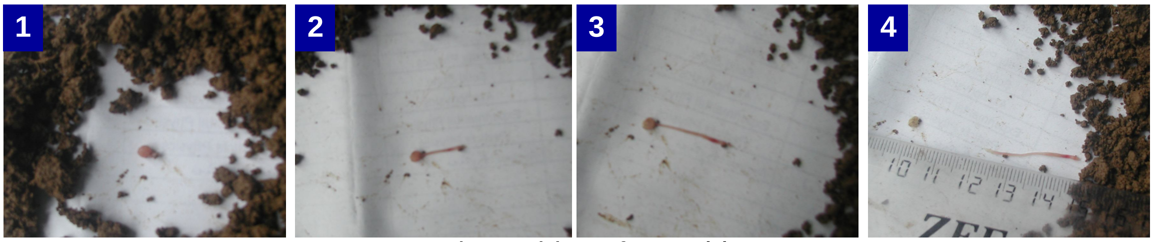
8. c) Worm cast of *P. excavatus*

Photo plate 8 : Earthworm and worm casts

9. a) Diapause earthworm



9. b) Soil pores made by earthworm burrowing



9. c) Hatching of *Drawida sp.*

.9. d) Earthworm coming out of worm cast

<u>Photo plate 9 : Earthworms (different actions)</u>

Chapter 5

Discussion

5.1. Earthworm species composition in mixed cropping agroforestry and plantations

The total number of earthworm species of the world reported till date varies from 3200 to 4200 (Fragoso *et al.,* 1994; Reynolds, 1998; James, 2000; Chanda *et al.,* 2003). The total number of species reported from India also varies from 402 to 509 (Julka, 1986; Tripathi and Bhardwaj, 2004a). The most recent number reported is 418 valid species/subspecies under 69 genera. The most diverse families in terms of recorded earthworm species are Megascolecidae followed by Octochaetidae and Moniligastridae (Julka *et al.,* 2007). In the present study it was observed that all three families mentioned above are represented in the State of Mizoram. Out of twelve earthworm species, five species (*Perionyx excavatus, P. macintoshi, Metaphire houletti, Amynthas alexandri* and *A. cortices*) belonged to the family Megascolecidae, four species (*Drawida sp., D. nagana, D. nepalensis* and *D. rangamatiana*) in Moniligastridae and three species (*Eutyphoeus assamensis, E. gigas* and *E. mizoramensis sp. nov.*) in Octochaetidae.

Studies on species composition from various parts of India indicate a well diversified nature of earthworms (Julka, 1986, 1988; Julka and Senapati, 1987; Mishra and Ramakrishnan, 1988; Ismael *et. al.,* 1990; Kale, 1997; Halder, 1998;

Chaudhuri and Bhattacharjee, 1999; Ramanujam *et. al.,* 2000; Chanda *et. al.,* 2003; Tripathi and Bhardwaj, 2004a).

Prior to the present study only one species of earthworm *viz. E. gigas* has been reported from the State of Mizoram (Julka, 1988). The present work has added eleven more species of earthworm recorded from four districts of the State. One of these species identified as *Eutyphoeus mizoramensis sp. nov.,* belonging to family Octochetidae, is new to science. The new species identified is closely related to *E. manipurensis manipurensis* Stephenson and *E. hastatus* Gates. It was collected from a place Sairang in the State of Mizoram at an altitude of 900 - 1100 m (Julka *et al*., 2005).

A brief description of the new species is given below:

External: Length 160-169 mm, diameter 6 mm, 143–247 segments. Prostomium tanylobic. First dorsal pore at 11/12. Clitellum annular, ⅓xiii-⅓xvii. Setae lumbricine, *aa* = 1.7-2.2 *ab* = 0.7-0.8 *bc* = 1.0-1.3 *cd* = 0.12-0.14 *dd* on segment 12, *aa* = 3.0-3.6 *ab* = 1.2-1.8 *bc* = 1.7-2.3 *cd* = 0.15 *dd* on segment 24. Avestibulate; openings of penisetal follicles in deep fissures on conspicuously protuberant, paired oval male porophores, at *b* lines, on segment 17; male pores paired, minute, each just behind penial setae on posterior lobe of male porophore. Female pores paired, minute, presetal, slightly median to *a* lines, on segment 14. Spermathecal pores paired, transverse slits, at *a* lines, in intersegmental furrow 7/8. Genital markings paired; postsetal, at *aa* or *bb* with median margins touching or close to each other, usually on segments 7, 16, 18, 19, 20, sometimes on 8, 21, 22, 23, 24; at *ab*, usually on segments 10-12, sometimes on 8, 9, 12, 16. Nephridiopores not recognized.

Internal: Pigment greyish. Septa 4/5/6, 8/9-10/11 muscular, 6/7/8 absent. Oesophagus with a large gizzard in a space between septa 5/6 and 8/9 and a pair of discrete hemi-ellipsoidal intramural calciferous glands in segment 12; intestine begins in segment 15; lateral intestinal caeca paired, broadly tubular, in segment 28; median, unpaired, ventral intestinal caeca 17-23, in segments 33-55; supra-intestinal glands 4-5 pairs, in segments 80-87; dorsal typhlosole simple, lamelliform, in segments ½ 27 to 80-84, lateral typhlosoles in segment 28. Dorsal blood vessel single, complete, extending anterior to gizzard into segment 3; last pair of hearts in segment 13. Holandric, testes and male funnels paired, enclosed in annular sacs, in segments 10 and 11; seminal vesicles paired, in segments 9 and 12, those of 12 extend to segments 14-15. Prostates tubular, paired, in segment 17, extending to segment 18. Penial setae ornamented with numerous, short, widely spaced, transverse rows of fine spines, tip pointed and slightly curved on one side, 2.29-2.32 mm long, 44 μ diameter. Spermathecae paired, in segment 8, each with a median and a lateral multiloculate shortly stalked posteriorly directed ental diverticula, each diverticulum opening into duct through a single opening; duct stout, somewhat conical, shorter than ampulla. Genital marking glands sessile, slightly protuberant in to body cavity (Figure 4 – 6). *Eutyphoeus mizoramensis* sp. nov. - 1. Genital region; 2. Penial seta; 3. Spermatheca.

E. *mizoramensis* belongs to a group of *Eutyphoeus* species with spermathecal pores at *ab*, male pores discharging directly on to body surface (avestibulate), holandric arrangement of testes, and short seminal vesicles in segment 12 (not extending beyond segment 20), and a complete dorsal blood vessel. It is distinguished from other species of the group *E*. *manipurensis manipurensis* Stephenson, 1921, and *E. hastatus* Gates, 1929.

The species inhabits orchards, plantations, agriculture fields and river beds with sandy clay loam soil (pH range of 4.9 - 6.5, moisture 20 - 26%) at 0 - 30 cm depth. It forms 2 - 5 cm high tower-like casts at the soil surface. The name of the species *mizoramensis* is derived from the State Mizoram in which its type locality is located.

Among the identified species of earthworms in the State, two species of *Perionyx*, two species of *Amynthas* and *Metaphire houlleti* belongs to family Megascolecidae, all three species of *Eutyphoeus* fall under family Octochaetidae and all the four species of *Drawida* belongs to family Moniligastridae. Some of the species recorded in the present study like *P. excavatus, M. houletti, A. alexandri, E. gigas,* and *D. nepalensis* have been reported from the neighbouring States of north-east region (Mishra and Ramakrishnan, 1988; Chaudhuri and Bhattacharjee, 1999; Halder, 1999). Earthworm species like *P. excavatus* found in Mamit district have also been reported from geographically nearer State of Tripura, whereas species like *Neloscolex strigosus, Tonoscolex horaii* and *Megascolides antrophyes* reported from relatively distant State of Meghalaya was not found in the present study. This may be due to the edaphic characteristics which may be similar in adjacent geographical areas.

Ecologically all three categories of earthworms *viz.* epigeic, anecic and endogeic species, as classified by Bouché (1977) were observed in different study sites. Rozen (1988) has shown that in temperate regions density of endogeic group of earthworms were highest in the spring and summer and lowest in winter from his studies in Poland. However, in the present study, it was observed that both epigeic and endogeic species were lowest or absent during winter season.

The vertical distribution of different earthworm species in SKT and PUC sites are in conformity with the characters described for different categories by Bouché (1977) except for *Eutyphoeus sp.* which were found on the surface soil. This may be due to the vertical upward movement of the endogeic species to the surface during the rainy season as reported by Card *et al.* (2006). Although four species of earthworms were common to both SKT and PUC, *P. excavatus* and *E. mizoramensis* sp. nov. were found in lesser number as compared to *Drawida* sp. and *M. houletti*. This may be attributed to the anecic nature of the *Drawida* sp. and *M. houletti* which makes them better adaptable as they are reported to exhibit geophytophagous feeding habit (Ismael, 1997).

Maximum number of species was recorded from Teak plantation, Orange plantation and Tlangnuam mixed plantation. It may be attributed to the high humus content from decomposition of leaf litter, well protected soil surface from sunlight, undisturbed niche, high moisture content, relatively high soil pH, C/N ratio, calcium, magnesium, aluminium and loamy texture of soil.

The earlier findings by various workers support the above findings (Evans and Guild, 1947; Mishra and Ramakrishnan, 1988; Werner and Dindal, 1989; Lavelle *et al.,* 1994; Fraser, 1994, Clapperton *et al.,* 1997; Clapperton, 1999; Gonzalez and Zou, 1999; James, 2000; Didden, 2001; Brown *et al.,* 2003, Ortiz and Fragoso, 2004; Nair *et al.,* 2005). *P. excavatus* and *Drawida sp*. are found in all four districts indicating their adaptability in varying soil conditions of different plantations. The order of versatility among the species was as follows – *Drawida sp. = P. excavatus* > *E. mizoramensis* > *M. houletti* > *D. rangamatiana = D. nepalensis* > *E. gigas* > *D. nagana = P. macintoshi = A. alexandri = A. cortices* > *E. assamensis*.

It was observed that *E. assamensis* distribution was restricted only to Tlangnuam mixed plantation. The restricted distribution may be due to the microniche which may be specific for the species. *Drawida nagana* which was one of the four species found in Teak plantation also had its distribution in Banana + Bamboo plantation irrespective of the soil type and the plants associated.

The pattern of distribution of earthworm species in different plantation observed in the present study have shown that there is a greater number of species available during the monsoon period. This is in line with the studies made by Bennour and Nair (1996) and Bhadauria and Ramakrishnan (1989). The lesser availability of number of earthworm species during dry winter season observed in the present study complies with the observation of Lofs Holmin (1983a), Senapati and Dash (1984) and Bhadauria *et al.* (1997). This observation on sparse distribution or absence of earthworm population may be associated with low soil moisture content and high temperature (Gerard, 1967; Phillipson *et al.,* 1976).

Earthworms are reported to get in to diapause stage during the dry months. Some endogeic earthworms reduced water loss and metabolic rates by getting in to diapause until favourable condition return (Mishra and Ramakrishnan, 1988; Edwards and Bohlen, 1996). In the present study such diapause stage was observed with *Drawida* species of earthworm during the dry season (Photo 9a).

It is known that the texture of the soil and soil pH influenced the distribution and number of earthworms. The loamy soil is known to favour the diversity earthworms whereas the sandy soil with low nutrients, coarse texture and acidic pH lower the diversity (El-Duweini and Ghabbour, 1965; Lee, 1985; Krishnamoorthy, 1989; Edwards and Bohlen, 1996; Curry, 1998). In the present study it was observed that the species diversity in Tlangnuam mixed plantation and Teak plantation with loamy soils were higher, while soils with course sandy like Banana plantation and Banana + Bamboo plantation harbored lesser species of earthworms. Other factors which might have influenced the species diversity may be poor soil nutrient and low moisture content and relatively acidic soil.

The occurrence of *P. macintoshi* in PUC in the rainy period may be attributed to the surrounding forest cover. A sandy but loose soil of river bank is the site where the new species *E. mizoramensis* sp. nov. was first collected in August 2003.

In general, mature and stable communities will have high diversity values (0.6 to 0.9 on a zero-to-one scale), seral communities or unstable communities under severe stress exhibit low diversity; usually nearer to zero on a zero-to-one scale (Odum, 1975). It was observed that study site SKT had higher value of *Simpson's index of dominance*, *D* and lower value of $\overline{H}$ as compared to PUC. Therefore the diversity of earthworm species was lesser in SKT. The higher diversity of earthworm species in PUC may be attributed to its surrounding forest cover.

Lower diversity of earthworm population in Banana plantation may be due to its soil character and land use practice. It is known that the frequency of weeding is carried out quite often in Banana plantation.

5.2. Earthworm community structure under different land use and farming practice

Earthworms form the major soil invertebrates and account for >80% of total invertebrate biomass (Dash, 1978; Lavelle, 1983a). Earthworm community structure in an agroecosystem is determined by the soil type (Fraser, 1994; Decaëns *et al.,* 2004), quantity and quality of organic matter added to the soil (Lavelle *et al.,* 1994) and the influences of disturbances (Werner and Dindal, 1989).

The present study reveals that density of earthworm was highest in forest area (Teak plantation) where humus content was relatively high compared to other study sites, whereas in Banana plantation the density was relatively less which may be due to lower humus level as result of weeding and higher degree of slope. It is reported that soil with more humus usually harbors larger number of earthworms (Gonzalez and Zou, 1999; James, 2000; Brown *et al.,* 2003; Ortiz and Fragoso, 2004).

It was observed that the earthworm density and biomass was higher in SKT compared to PUC. This may be due to higher nutrient availability in the soils of SKT which was left as a fallow before taking up for plantation as agroforestry field. In both SKT and PUC the density was slightly higher in the first year of study compared to second and third year. There was a seasonal variation in earthworm population in both study sites. The peak density of earthworm population was observed during the monsoon season.

In general, it was observed that the seasonal density followed a bimodal pattern in each year of the study in PCL plantations of both SKT and PUC sites. Similar bimodal pattern in density have been reported in the rain-fed agriculture lands of Central Himalayas (Mishra and Ramakrishnan, 1988). The differential response of density and biomass in SKT in the second and third year of study may be due to the higher density of smaller sized worms like *Drawida sp*.

Studies on earthworm biomass in PCL plantation of both SKT and PUC sites have shown that in the first year the biomass was quite high and there was a sudden reduction in the second and third year. The sudden fall in biomass may be due to depletion in availability of food supply as suggested by Mishra and Ramakrishnan (1988). Soon after monsoon there was a sudden raise in earthworm biomass which may be attributed to the maximum availability of food materials and higher moisture content of the soil following rains. Growth rates might have been enhanced by the higher food intake. It has been suggested that earthworms with more food availability gain weight faster than those with little or no supplementary food (Abbot and Parker, 1981; Muldowney *et al.,* 2003). Increased soil moisture, temperature and microbial activity results in significant increased in growth rate in earthworm population (Fragoso and Lavelle, 1992; Valle *et al.,* 1997; Eriksen-Hamel and Whalen, 2006).

Maximum density of juvenile and immature worms during June - July and highest adult density between September - October was observed in PUC. It has been reported that a juvenile population was dominant during the summer followed by an increase in sub-adults and adults during the autumn, winter and spring seasons. (Thambi and Dash, 1973; Senapati and Dash, 1984; Bennour and Nair, 1996). Sahu *et al*. (1988) suggested that a decrease in juvenile and immature worms after monsoon season could be due to transformation of young worms in to adults and/or high mortality and/or discontinuous reproduction resulting in an unstability in the age structure. However, Baker (1983) observed a greater total density and biomass of earthworms in temperate regions of Ireland where the soil was drier.

Strata-wise studies on earthworm density and biomass indicate that the upper strata (0 – 10 cm) having higher percentage of organic matter is most suitable for harboring the maximum number of worms both at SKT and PUC. The finding of decreased earthworm density and biomass with increasing soil depth in study sites is supported by Kaushal *et al.* (1995) and Bisht *et al.* (2003) who found the highest density and biomass in the top (0 -10 cm layer) soil. The higher density of *Drawida sp*. in the lower strata during the dry season shows the vertical movements of the anecic species. The lesser density or absence of worms in the lower most strata (20 - 30 cm) indicates that the soil in the lower strata is not suitable for majority of the earthworm species recorded in the study sites. This may be due to lack of food material and lower moisture content. The presence of greater number and biomass of earthworm species in 0 – 10 cm in PCL plantation of SKT may be related to availability of food materials and high soil moisture content. A strong positive correlation between earthworm biomass and increased soil moisture content has been reported by Wood (1974). Higher density and biomass in 10 – 20 cm strata during the dry season may be due to presence of relatively higher moisture content subsurface. The depth of soil has been shown to be a significant factor governing earthworm distribution in both temperate soil and tropical forest soil (Philipson *et al.*, 1976; Fragoso and Lavelle, 1992).

The studies on strata-wise population of different age groups revealed that juvenile and immature group could survived better in the second year of study. Highest juvenile density at the surface layer (0 - 10cm) in August may be due to hatching of cocoons during pre-monsoon rainy months (May - July), which is an active breeding period. It has been reported that during the active breeding period there was a larger proportion of juvenile and immature populations compared to mature ones (Evans and Guild, 1948). The other reason may be the loose nature of soil and better access to food for the young worms. Sahu *et al.* (1988) have reported restricted availability of juvenile and immature worms in 0 - 5 cm soil depth which was attributed to higher environmental fluctuations in the top soil. A very low density or total absence and low biomass of juvenile and immature worms at 20 - 30 cm depth may also be due to more compact structure of soil profile in deeper soils.

Both positive and negative influence of various land use and farming practices like, irrigation and drainage (Edwards *et al.,* 1995), conservation tillage (Barnes and Ellis 1979; Gerard and Hay, 1979; Edwards and Lofty, 1982c; Lal, 1982; House, 1985; Rovira *et al.,* 1987; Bohlen *et al.,* 1995; Jordan *et al.,* 1997) and direct drilling (Andersen, 1987; Francis *et al.,* 1987) have been reported to have positive effect on earthworm population, while land use practices like tilling (Gerard and Hay, 1979; Edwards, 1983; Mackay and Kladivko, 1985; Haukka, 1988; Brown *et al.,* 2003; Birkas *et. al.,* 2004), jhuming (slash and burn) (Critchley *et al.,* 1979; Bhadauria and Ramakrishnan, 1989; Lavelle and Pashanasi, 1989), ploughing (Wyn and Glanteller, 1992; Smeaton *et al.,* 2003), stubble burnt situation (Mele and Carter, 1999), deforestation (Dotson and Kalisz, 1989; Bhadauria *et al.,* 1997; Blanchart and Julka, 1997), cultivation on successive years (Springett *et al.,* 1992; Fraser, 1994; Friend and Chan, 1995; Paoletti, 1999; Curry *et al.,* 2002) and other agriculture management (Boström, 1986; Edwards *et al.,* 1995; Edwards and Bohlen, 1996; Binet *et al.,* 1997;

Clapperton *et al.,* 1997; Zou and Gonzalez, 1997; Paoletti *et al.,* 1998; Chan, 2001) on the earthworm community are known to have negative effect.

Darlong and Alfred (1991) did not find any loss or replacement of earthworms by another species in slash and burn situation.

The present findings on reduction in density in the third year of study and biomass in the second and third year in PCL plantation at both SKT and PUC indicate a negative impact of land use practice like weeding on earthworm communities. This may be attributed to the fact that weeding might have resulted in habitat disturbance and/or destruction, reduced soil moisture and soil compaction by agricultural traffic (Boström, 1986). Regular weeding might have resulted in removal of the available food material from the surface and also brings direct sunlight to soil surface. This will ultimately reduce soil moisture and increase soil temperature that cause decline in earthworm density. It may also be due to changes in food supply (Tian *et al.,* 2000).

This negative impact of various land use practices may be attributed to mechanical damage during cultivation, loss of the insulating layer of vegetation, decreased supply of food as organic matter which gradually decreases or predation by birds.

In the present study the highest species diversity was seen in mixed plantations (non-jhumed area), followed by orchards, forest and jhumed cultivation. The lesser diversity in jhumed cultivation may be due to absence of permanent vegetation. Balesdent *et al.* (1988) are of the opinion that the adverse indirect effect of cultivation on earthworm may include increase soil surface temperature and moisture reduction due to absence of a permanent vegetation cover and reduced litter input. Friend and Chan (1995) have reported a negative influence of cropping on the population of earthworm in New South Wales. Senapati *et al.* (2002) observed a reduction in earthworm population of about 77% and 44.5% of epigeic and endogeic worm after burning the slashed vegetation.

There are number of reports on the effects of vegetation on earthworm species composition and distribution (Gonzalez *et al*., 1999; Bhadauria *et al.,* 2000; Didden, 2001). The present study did not find conclusive decision on the effect of vegetation on earthworm community structure. Since Tlangnuam mixed plantation with nine different plant species and Orange plantation with only two associated plant species harbors almost the same number of earthworm species. This result is supported by studies done by Phillipson *et al.* (1976). Blanchart and Julka (1997) did not find clear relation between density or biomass and vegetation, soil characteristics or topography. But in other study, Gonzalez *et al*. (1999) and Bhadauria *et al.* (2000) have stated that earthworm abundance, density and distribution are determined by its vegetation. Didden (2001) found no epigeic species in horticultural land.

Farming practice like weeding adapted for the maintenance of agroforestry plots of SKT and PUC might have reduced the surface cover in the second and the third year resulting in decline of earthworm density and biomass. Earlier studies of Weste Rnacher and Graff (1987) support the above view.

The presence of *Drawida* species in most of the study sites and throughout the study periods indicates that it as a hardy species to withstand the adverse effect of land use and farming practices. Similar observation are made by Bhadauria *et al.* (1997), who noted that the *Drawida* species that has high ability to withstand disturbances caused by intensive agricultural practices. Similarly, Bhadauria *et al.* (2000) suggested that the high density of *Drawida sp*. in a pine forest may be attributed to higher preference for sites where mineral soil is relatively free of organic matter deposits in the surface layers.

Hauser and Asawlam (1998) are of the opinion that earthworms are strongly affected by the type of fallow management system and the cover crops used.

5.3. Effects of rainfall and soil Physico-chemical characteristics on earthworm population dynamics.

The physical and chemical parameters of soil are inter-related. For example, an increase in rainfall increases the soil moisture content which is also influenced by temperature. In the present study, some of these physical soil characteristics though correlated with each other, were not significantly different in the two study sites SKT and PUC. Therefore, this may be one of the reasons for distribution of almost same species both in SKT and PUC. The difference in density, biomass which was observed in the two study sites may be due to differences seen in some of the edaphic factors like organic and inorganic nutrient levels, altitude, soil texture and associated plant species of the two sites. It is suggested that under similar climatic conditions, factors that determine earthworm abundance and distribution may depend on plant species composition and on the physical and chemical properties of soil within a plant community (Lee, 1985; Berry, 1994; Gonzalez *et al.*, 1996).

Physiologically, earthworms are moist skinned animals and therefore, require moist environment which is dependent on the rainfall. In the present study, the population dynamics followed the variations seen in rainfall. The peak population coincided with the high rainfall period. A positive correlation ($p < 0.01$) between the rainfall and earthworm abundance was found in both study sites. Similar observation is reported by other workers (Lofs Holmin, 1983a; Mishra and Ramakrishnan, 1988; Sahu *et al.,* 1988; Bhadauria and Ramakrishnan, 1989; Reddy and Pasha, 1993; Bhadauria *et al.,* 1997). There are reports that the earthworm population density and biomass were high in the rainy and early winter season and low in summer (Kaushal and Bisht, 1994; Bhadauria and Ramakrishnan, 1989).

Soil temperature is another important factor influencing the structure, composition and abundance of earthworm population (Lavelle, 1983b; Lavelle *et al.,* 1989). Soil temperature is correlated with the rainfall and the soil moisture content as observed in the present study. High soil temperatures are often associated with moisture shortages which results in seasonal earthworm mortality and hence very low or no density (Gerard, 1967; Phillipson *et al.,* 1976).

Lee (1985) has suggested that the soil temperature range of 17.8^{o}C to 28.93^{o}C is quiet suitable for earthworms. Dash and Senapati (1980) have proposed 20 – 30^{o}C soil temperature to be most favourable range for tropical and sub-tropical earthworms. The result of the present study indicates the tolerance of a few earthworm species during the winter months, at a temperature lower than the one observed by Dash and Senapati (1980). This may be an adaptation to the low range of temperature in higher altitudes of Mizoram.

As observed in many of the earlier works (Bhadauria *et al*., 1997, 2000; Valle *et al*., 1997) the total density and biomass of earthworm population were higher during the relatively higher temperature period. Dash and Senapati (1982) observed mortality of worms at a temperature $\leq 15^{o}$C and $\geq 35^{o}$C. Sahu *et al.,* 1988 reported a zero population at 31^{o}C soil temperature. Similar to the above observations the density of earthworm population was recorded higher in the high temperature months and were negligible or absence during winter months when as low as 10^{o}C. To avoid these adverse effects, earthworms are known to migrate downward to a deeper soil (Reddy, 1983; Reddy and Pasha, 1993). Though there was a variation in biomass with temperature, it was found that there is no significant correlation.

Curry (1998) opined that on a global scale, temperature is the climatic variable of greatest significance, because it determines metabolic rates and the diversity of food resources, but on a more local scale moisture restriction often determines patterns of distribution and activity.

Soil moisture content plays a crucial role in earthworm community structure (Evans and Guild, 1947). The density of earthworm in the present study is positively correlated ($P < 0.01$) with the moisture content of the soil. Similar observations are made by many researchers (Evans and Guild, 1947; Thambi and Dash, 1973; Bennour and Nair, 1996; Baker, 1998; Whalen *et al*., 1998; Aroujo and Hernandez, 1999; James, 2000; Tian *et al.,* 2000). Optimum soil moisture content varies for different species and ecological groups, and within species there appears to be a considerable capacity to adapt to local conditions (Lee, 1985). The fluctuation in the densities of different earthworm species seen in the study sites with changed moisture content of soil in different months may be adaptation to the local conditions as mentioned above.

Earthworms are most active in optimum moisture content (Lavelle, 1974; Nordström, 1975; Nordström and Rundgren, 1974; Baker *et al.,* 1993). According to Madge (1969) earthworm prefer soils with moisture between 12.5 - 17.2%. Dash and Senapati (1980) proposed moisture condition of around 10 - 20% as most favourable range for tropical earthworms. The presence of earthworms of Mizoram which were found in the range of 10 – 28% of soil moisture that fall in the above range (10 - 20%) seem to be better adapted for higher moisture content.

Bennour and Nair (1996) find out a positive correlation of the moisture and an inverse correlation of soil temperature on the density and biomass of earthworms.

The correlation between earthworm population and soil physical characters in ML plantations of both sites could not be established due to short duration of the crop.

Observations of Lavelle (1997), Price and Gordon (1999) and Shipitalo and Le Banayon (2004) have shown that water holding capacity and porosity are influenced by the presence of earthworms. According to Lamandè *et al.* (2003) earthworms are known to produce structural features at three different scales of soil porosity. Görres e*t al.* (2001) concludes that anecic earthworms cause statistically significant changes in the pore structure of soil through burrowing and casting. The bulk density of soil largely depends on the particle density and clay content whereas porosity depends on the bulk density and status of organic matter (Singh, 1983). However, in the present study, soil porosity, water holding capacity and bulk density of both SKT and PUC agroforestry sites were not influenced by earthworm density or biomass. Though the distribution and high abundance of anecic worms like *Drawida sp.* were seen it did not have significant effects on any of the above parameters.

One of the important factors which influence the density and biomass of earthworm population is the inorganic nutrients in the soil. Asawalam (2006) has reported a significant reduction of organic carbon, total nitrogen, available phosphorus and exchangeable potassium in the top 0 - 5 cm of soil after continuous cropping. On the other hand, Tian *et al.* (2000) observed a higher pH, Organic carbon, available P in fallow land associated with the leaves of plant species having greater decomposition rates. Higher density in SKT compared to PUC may be due to its higher inorganic nutrients.

Soil pH is often cited as a limiting factor on earthworm distribution (Edwards and Bohlen, 1996; James, 2000). The general acidity in the soils is partly related to highly leached soils and slower litter decomposition (Mishra and Ramakrishnan, 1988). Edward and Lofty (1972) suggest that earthworm species have a narrow range in pH tolerance. There are reports that acidic soil having low pH (below pH < 3.5) is associated with very low density or total absence of earthworm (Curry, 1998; Mele and Carter, 1999). However, a relatively increase in pH from 7.25 to 8.25 is reported to decreases earthworm numbers in Egyptian soils (El-Duweini and Ghabbour, 1965). Among the different sites surveyed, the high soil pH was found in Tlangnuam mixed plantation and Teak plantation where earthworm species diversity was also relatively high as compared to SKT and PUC sites having lower pH. This indicates that pH may be one of the important factors in determining the diversity of earthworm other than the density as reported by many researchers (Bhadauria and Ramakrishnan, 1989). It has also been reported by some workers that the density of earthworm positively influences the soil pH (Nye, 1955; Sharpley and Sayers, 1976). In the present study, there was a significant correlation between soil pH and earthworm density in PCL plantation of PUC and ML plantation of SKT ($P < 0.05$), while there was no significant correlation between pH and earthworm biomass in any of sites.

Monthly variations in soil pH of the SKT and PUC have shown relatively similar fluctuations and were found to be acidic. However a slightly higher soil pH of SKT might have resulted in higher density of earthworms. The five species of earthworm found in both experimental agroforestry sites indicate higher tolerance limits. A few species like *E. assamensis* and *A. alexandri* found in Teak and Tlangnuam mixed plantation seem to be restricted only to high soil pH. Several experiments have shown that some species of earthworms have special tolerance limits to soil acidity, and that they avoid unfavourable pH levels (Sigmund, 1987). There may be optimum species specific pH range which governs the distribution of earthworms. Tripathi and Bhadarwaj (2004c) have given optimum pH of 6.5 and 7.5 for *Eisenia foetida* and *Lampito mauritii* respectively.

Different researchers proposed different range of optimum soil pH for earthworms. A pH range of 4.9 - 7.4 is put forth for majority of temperate earthworms (Satchell, 1967; Michalis *et al.,* 1989), whereas the tropical earthworms of India have been reported from a wider pH range of 5.0 – 8.4. The upper range of pH for earthworms in north-eastern region seems to be at a slightly lower level (pH 7.33) (Bhattacharya and Chakraborti, 1987; Bhadauria and Ramakrishnan, 1989; Nainawat and Nagendra, 2001). The presence of different species of earthworm found in Mizoram was well within the range given for the north-eastern region except for the experimental agroforestry study sites at SKT and PUC which was slightly below the range even considering at national level.

There is a definite relation between the percentage of soil organic carbon and soil organic matter. Soil organic matter consists of a wide range of compounds forming a biochemical continuum from cellular fractions of higher plant, microbial and animal origin (Anderson and Ingram, 1993). Soil organic matter is found to be one of the factors that determine composition of earthworm communities (Curry, 1976; Marshall, 1977; Edwards and Lofty, 1979). Since organic matter provides food base for the earthworm community, it can sometimes be a good predictor of earthworm abundance (Curry, 1998). The highest percentage of organic carbon in Tlangnuam mixed plantation may be attributed to litter quality which can be easily decomposed. Curry (1998) has shown that litter input largely determines the soil organic matter.

Research findings relating to correlation between earthworm density and the percentage of soil organic carbon support both a positive (El-Duwieni and Ghabbour, 1965; Kale and Krishnamoorthy, 1981; Hendrix *et al.,* 1992; Scullion and Malik, 2000; Tian *et al.,* 2000; Shuster *et al.,* 2001, 2002; Brown *et al.,* 2003; Tripathi and Bhardwaj, 2004b; Liu *et al*., 2004) and negative (Jordan *et al.,* 2000; Desjardins *et al.,* 2004) inference. In the present study, there was a significant correlation ($P < 0.05$) between earthworm density and soil organic carbon in PCL plantation of SKT. However, in PUC site and ML plantations of both SKT and PUC it was not significant.

Contradictory to the present finding, Boag *et al.* (1997) found no relation of soil moisture, soil texture, organic matter or pH with the make up of earthworm populations. However, Lehman (2005) concluded that abiotic factors like moisture, nitrate, phosphate, and organic matter content in soil and leaf litter were not significantly correlated to earthworm distribution.

The higher density of earthworm population in Tlangnuam mixed plantation may be related to maximum soil nitrogen content in the soil. High litter input from the plant debris in the Tlangnuam mixed plantation might have been mineralized by larger number of earthworms. The lowest percentage of soil nitrogen in Banana plantation may also be related to lower density of earthworm. Curry *et al*. (1995) reported that earthworms contribute additional mineral nitrogen to soil. This is consistent with the present finding that explains the presence of higher nitrogen content in Tlangnuam mixed plantation.

A significant correlation ($P < 0.01$) between soil nitrogen and earthworm density seen in PCL plantation of SKT complies with the observations made by Barros *et al.* (2004) and Dominguez *et al.* (2004). The observations made by Kale and Krishnamoorthy (1981) shows that the correlation between soil nitrogen and density of earthworm is species specific. Aroujo *et al.* (2004) and Paul and Vanlalchhuanga (2004) have reported that earthworms are known to increase available soil nitrogen.

Studies have shown that high earthworm density is associated with high C/N ratio (Kale and Krishnamoorthy, 1977, 1981; Callejo *et al.,* 1985). The present study showed a significant positive correlation ($P < 0.01$) between C/N ratio and earthworm density in PCL plantation of PUC agroforestry site similar to earlier studies. There are also reports on negative correlation between C/N ratio and earthworm density (Ruz Jerez *et al.,* 1988; Hendrikson, 1990). However, though there was no negative correlation observed in the present study.

The variation in dynamics of C/N ratio being highest during August of the first year and lowest in the third year may be related to the existing density of earthworm. It was observed that C/N ratio of soil decreases with increasing depth. Similar observation has been made by Singh and Datta (1988) and Kaushal *et al.* (1995).

Kale and Krishnamoorthy (1981) have reported species-wise effect of C/N ratio. *Lampito mauritii* and *Pentoscolex corethrus* are abundant in soils with high C/N ratio, whereas *Perionyx excavatus* is found in low C/N ratio soils. In the present study *Drawida sp*. was found more frequently at higher C/N ratio and *M. houletti* was associated with lower C/N ratio.

A significant positive correlation ($P < 0.01$) observed between phosphorus and earthworm density indicates the importance of phosphorus as one of the inorganic nutrients required for the presence of earthworms.

The studies on fallows made by Tian *et al.* (2000) and Suárez *et al.* (2003) suggest that earthworms significantly increased the amount of readily exchangeable phosphorus in the soil.

It was observed that the available potassium was at much higher level as compared to phosphorus. However, in the present study very high levels of available potassium may also be due to its higher leaching character as compared to available phosphorus.

The highest content of available potassium in Teak plantation and SKT coincided with earthworm density. These results are similar to the results obtained by Reddy and Pasha (1993). Thus significant correlation ($P < 0.05$) between potassium and earthworm biomass in PCL plantation of SKT indicates the possible involvement of potassium on earthworm secondary production.

A decrease in available potassium with increasing depth was observed in the present study which might have resulted in lesser earthworm density in the lower strata. Singh and Datta (1986) have also reported a depletion of potassium levels in deeper soils of Mizoram.

Two climatic factors – rainfall and moisture were found to have a significant correlation ($P < 0.01$) with biomass of earthworms in PCL of both sites. Among the chemical factors, only potassium was found to have a significant correlation ($P < 0.05$) with earthworm biomass in SKT.

It may be stated from the above studies that the synergistic effect of on physical parameters in PCL plantation of both SKT and PUC agroforestry sites had relatively more influence on abundance and population dynamics of earthworms as compared to chemical components.

In addition to others factors like pH, organic matter and moisture, calcium and magnesium are also important factors explaining the composition of the earthworm fauna (Fragoso and Lavelle, 1992; Didden, 2001).

5.4. Secondary production

Studies on secondary production of an ecosystem will give an assessment of its primary production as both are inter-related. The studies of Dash and Patra (1977) shown utilization of 15% of primary production of energy by earthworms in grassland. Secondary productivities of few species of earthworm have been reported from different parts of the world (Lakhani and Satchell, 1970; Satchell, 1971; Nowak, 1975; Dash and Patra, 1977; Lavelle, 1978; Senapati and Dash, 1981; Sahu and Senapati, 1986). It has been reported that the earthworms of tropical climate are more productive in comparison with those of temperate climate (Sahu and Senapati, 1986). Secondary production is affected by grazing stress, flooding stress and agrochemical stress, which are shown to enhanced secondary production in pastures (Senapati and Dash, 1983; Senapati *et al.,* 1987).

Study site SKT has a higher earthworm biomass compared to PUC. The higher secondary production of earthworms in SKT compared to PUC may be related to biomass of earthworms. Reduction of secondary production in the third year of study follows the reduction in biomass due to farming practice and availability of food. The total secondary production in both PCL plantations of SKT and PUC agroforestry system was significantly higher in the first year of study (2003) compared to that of second year (2004). This may be due to sudden fall in the biomass of earthworm due to the reasons mentioned earlier. The values for secondary production obtained in the first year of study in both SKT and PUC was much higher than earlier studies. Dash *et al.* (1974) have reported a secondary production of 162 kcal/m^2/year, Senapati and Dash (1983) have reported 678 kJ/m^2/yr in low land and 511 kJ/m^2/year in the upland side of Orissa.

It was observed from the strata-wise studies carried out in the second year that secondary production of earthworms declined with increasing depth following the trend shown by the biomass.

5.5. Worm cast production and its nutrient status in relation to adjacent soil

Earthworm burrows through the earth and consumes large quantities of soil and fresh or partially decomposed organic matter from the soil surface, depositing it as fecal matter or casts. Similarly, soil from the sub-soil horizon is moved by these worms to the upper levels where it is mixed with the surface soil, resulting in a more uniform distribution of soil nutrients. Darwin (1881) estimated that about 10.6 tons of materials are brought to the soil surface of each acre by earthworms.

Various researchers have made studies on the worm cast production in different plantations of different regions. Sharpley and Syers (1979) reported casting activity between April to September with maximum activity in June in temperate regions. Singh and Dev (1987) also reported a maximum amount of casting produced by the worms in the month of June in tropical region. Bhadauria and Ramakrishnan (1991) have reported the maximum cast production in pine forest of north-eastern region during monsoon period. This is in compliance with the present result which shows that worm cast production was found mainly between June to October from both study sites coinciding with the monsoon period.

Bhadauria and Ramakrishnan (1991) have reported cast production rates of 40.6 t $ha^{-1}y^{-1}$ from Khasi Pine forest of Meghalaya, Nye (1955) reported 50.4 t $ha^{-1}y^{-1}$ from Ghana, Satchell (1967) reported about 0.1 t $ha^{-1}y^{-1}$ and Dash and Patra (1979) reported 31.1 tons dry weight/acre/year in grassland site of Orissa. In the present study the total worm cast production was found to be in the range of 7.1 - 9.5 t $ha^{-1}y^{-1}$ in PCL plantation of SKT and 0.26 – 1.03 t $ha^{-1}y^{-1}$ in PCL plantation of PUC. These values are much lower than the values reported earlier studies done mostly in natural forest area. The lower production in the present study may be attributed partly to the lesser abundance of cast producing species of earthworm and also low organic matter production in the early stages of the agroforestry sites.

The production of worm cast is known to be influenced by soil water content, soil temperature (Norgrove *et al.,* 2003; Whalen *et al.,* 2004), vegetations and environmental conditions (Daniel *et al.,* 1996), land use pattern (Norgrove and Hauser, 2000), shading and litter fall (Hauser, 1993), earthworm species assemblages (Birang *et al.,* 2004). Hauser and Asawalam (1998) opined that reduction in casting was related both to degree of biomass removal and re-establishment of cover crops, at the same time, surface casting activity was not related to concentrations of organic carbon, total nitrogen, exchangeable calcium and magnesium. Sharpley and Syers (1979) suggested that seasonal variations in cast production were attributed to fluctuations in food supply, soil moisture and in temperature. Farenhorst and Bowman (2000) found no significant differences in cast production rates among earthworms fed different foods.

The highest production of worm cast in Tlangnuam mixed plantation may be related with adequate food supply and moisture content for the cast producing species like *Eutyphoeus sp*. The lowest cast production in PUC, Banana plantation and Banana + Bamboo plantation may be attributed to soil type, less organic matter and less abundant of earthworm species which produce cast. It was observed that the dominant species found was *Drawida sp*.

Higher total cast production in PCL plantation of SKT compared to PUC may be attributed to higher density of earthworm population in SKT and difference in soil texture which could carry higher organic matter. Further reduction of worm cast production in the second and third year may be due to decline in earthworm biomass and food supply after repeated weeding as suggested by Sharpley and Syers (1979). A gradual decline during the second year and the presence of cast only during the month of August in the third year of study may also be attributed to a sharp decline in biomass.

In the present study no correlation was found between Worm cast production and soil chemical properties except for phosphorus in PUC. This is in agreement with Hauser and Asawalam (1998) observations.

Worm cast was found to have a higher nutrient compared to adjacent soil. The moisture content, pH, organic carbon and inorganic nutrients like nitrogen, phosphorus and potassium of soil were significantly higher in worm cast compared to adjacent soil. These results are supported by earlier findings of many workers (Nye, 1955; Madge, 1969; Syers *et al.,* 1979; Vurma and Chauhan, 1979; Reddy, 1983; Krishnamoorthy and Vajranabhaiah, 1986; Bhattacharya and Chakraborti, 1987; Gupta and Sakal, 1987; Edwards, 1988; Bhadauria and Ramakrishnan, 1989; Zhang and Schrader, 1993; Hauser and Asawalam, 1998; Sculion *et al.,* 2002).

Syers *et al.* (1979) have suggested that the high concentrations of chemical quality of worm casts may be attributed to selective feeding on nutrient-rich organic materials in the soil by earthworms. Shipitalo *et al.* (1988) suggested that the nature and amount of organic matter in earthworm surface castings is dependent on the food source available to the earthworms. Norgrove *et al.* (2003) pointed out that earthworm casts derived from mulched plots had higher N and K concentrations than those from non-mulched plots. The enrichment of earthworm casts in essential plant nutrients such as N, P, K, Ca and Mg has been demonstrated by several workers (Lunt and Jacobson, 1944; Parle, 1963; Graff, 1970). Krishnamoorthy (1990) observed that worm casts have all major components that are essential (NPK) to regard them as field fertilizers.

Higher pH value in worm cast compared to adjacent soil observed in the present study is supported by Nye (1955), Vurma and Chauhan (1979), Bhattacharya and Chakraborti (1987) and Bhadauria and Ramakrishnan (1989). Higher pH in cast is probably due to the ammonia secreted in the intestine which may acts as a neutralizing factor (Wallwork, 1983). However, Nijhawan and Kanwar (1952) noted a lower pH value for the worm cast than adjacent soils in Punjab.

Most of the earlier observations found higher nitrogen in worm cast compared to adjacent soils (Lunt and Jacobson, 1944; Parle, 1963; Graff, 1970; Patra, 1975; Dash and Patra, 1979; Syers *et al.,* 1979; Edwards, 1988; Ruz Jerez *et al.,* 1988; Simek and Pizl, 1989; Krishnamoorthy, 1990; Parkin and Berry, 1994; Aroujo *et al.,* 2004). Simek and Pizl (1989) suggests that Nitrogen fixing bacteria are found in the gut of earthworms and in earthworm casts which helps in nitrogen mineralization.

Similarly, in the present study the percentage of nitrogen content of worm cast was higher than adjacent. However, Bhattacharya and Chakraborti (1987) have found lower nitrogen in adjacent soil compared to worm cast.

Elliot *et al.* (1990) have found that earthworm casts generally have a higher ammonium concentration and water-holding capacity than bulk soil samples, and they constitute sites of high denitrification potential. The concentration of $NH4^{+}$ in the casts of earthworms can increase during gut passage of the ingested soil and after the soil material has been egested as castings. Bohlen and Edwards (1995) stated that earthworms had significant effects on the amount of extractable NO_3^-, which increased with time.

Bossuyt *et al.* (2005) reported that soil organic carbon was protected within worm cast by micro-aggregates within large macro-aggregates leading to a possible long-term stabilization of soil carbon. Asawalam (2006) reported a strong linear association between the quantity of casts and the amount of organic carbon and other nutrients in casts. Bhattacharya and Chakraborti (1987) observed lower organic carbon from their studies in the cast of Tripura.

The present study observes a higher organic carbon in the worm cast compared to adjacent soil. The works of earlier researchers support the present result. (Madge, 1969; Gupta and Sakal, 1987; Reddy, 1983; Zhang and Schrader, 1993; Sculion *et al.,* 2002; Asawalam, 2006).

Other inorganic nutrients like potassium and phosphorus were also found to be significantly higher in worm cast compared to surrounding soil in the present study. Similar observations were made by Barley (1961), Gupta and Sakal (1987), Graff (1970), Vimmerstedt and Finney (1973), Sharpley and Syers (1976), Mansell *et al.* (1981), Satchell and Martin (1984), Satchell *et al.* (1984), Edwards (1988), Basker *et al.* (1994), Sculion *et al.* (2002) and Kuczak *et al.* (2006). Sharpley and Syers (1976) noted that the surface casts contain approximately four times more loosely bound inorganic P and two times as much as loosely bound organic P as underlying soil.

There are reports on alkaline phosphatase excretion in worm casts (Satchell and Martin, 1984; Satchell *et al.,* 1984). Sharpley and Syers (1976) and Mansell *et al.* (1981) are also of the opinion that worm casts are not only richer in soluble inorganic phosphates but also in exchangeable phosphorus. Higher phosphatase activity of worm cast than that of the undigested soil increases the mineralization inorganic phosphorus (Sharpley and Syers, 1976; Mansell *et al.,* 1981; Satchell and Martin, 1984; Satchell *et al.,* 1984; Krishnamoorthy, 1990).

The higher nutrient level in the worm cast compared to adjacent soil is reported to be due to microbial activity in the earthworm gut (McGarity and Myers, 1967; Dkhar and Mishra, 1983, 1986; Edwards, 1994; Cortez and Bouche, 1998; Bano *et al.,* 1987).

Earthworm casts typically have higher microbial biomass and respiration rate than bulk soil (Scheu, 1987; Lavelle *et al.,* 1992; Mishra and Dkhar, 1992). Soil microorganisms live in the worm's gut as well as the surrounding soil and so the microbial content of casts is usually more concentrated than in surrounding soil. Microbial activity in worm casts is 10 to 20 times higher than in the soil and organic matter that the worm ingests (Dkhar and Mishra, 1986; Edwards, 1994).

Earthworm excreta (castings) are an excellent soil-conditioning material with a high water holding capacity and a natural time release for releasing nitrogen into the soil (Harris *et al.,* 1990).

From their comparative study between casts and surface soil, Vleechauwer and Lal (1981) found the presence of less sand, more silt and clay in the casts. They also found that casts had greater bulk density and structural stability than the surface soil. The higher amount of N, organic matter content, available P and cation exchange capacity were also estimated from the worm's casts. Therefore, all these characteristics qualified the worm cast as bio-fertilizer.

C/N ratio is a measure of litter degradation in soils. The present study reveals that worm casts generally possess higher C/N ratio compared to adjacent soil. This result is consistent with Nijhawan and Kanwar (1952), Julka and Mukherjee (1984), Krishnamoorthy (1984) and Kale and Krishnamoorthy (1977). Bhattacharya and Chakraborti (1987) reported species specificity in C/N ratio.

5.6. Effect of fertilizers (NPK) on earthworm population

Inorganic fertilizer plays a vital role in modern agriculture and increased used of fertilizers to boost the productivity is a common practice. Normally the use of inorganic fertilizers is reported to have a positive impact on earthworm number. This is probably an indirect effect of increased crop biomass production and consequent increases in organic residues (Edward and Bohlen, 1996; Edward *et al*., 1995). Hendrix *et al.* (1992) reported number in meadows receiving inorganic fertilizer average nearly twice the earthworms compared to unfertilized meadows.

In general, application of inorganic fertilizer is found to increase the earthworm populations (Watkin and Wheeler, 1966; Zajonic, 1970; Gerard and Hay, 1979; Edwards and Lofty, 1982a,b; Lofs-Holmin, 1983a; Reddy and Ground, 1987; Boström, 1988; Mishra and Tripathy, 1988; Hendrix *et al.,* 1992; Tiwari, 1993; Kale, 1997; Callaham *et al.,* 2003; Muldowney *et al.,* 2003; Sjoerd, 2003; Steffey, 2003).

Adverse effect of inorganic fertilizers especially indiscriminate application and those which have a strong acidic effect have been reported by a number of researchers. (Edwards and Lofty, 1974, 1975; Zajonic, 1975; Nowak, 1976; Gerard and Hay, 1979; Edwards, 1983; Potter *et al.,* 1985; Scullion and Ramshaw, 1987; Brussard and De Ridder, 1990; Ma *et al.,* 1990; Edwards *et al.,* 1995; Sahu *et al*., 1995; Donahue, 2001). The reason for the negative effect may be the acidifying effect of the inorganic fertilizers and also due to toxic effect of ammonia.

There was an enhancement of earthworm population density in PCL plantation of both SKT and PUC agroforestry sites. These findings are in accordance with the earlier studies where applications of fertilizers are used judiciously. This positive effect of inorganic fertilizer on earthworms may be attributed to greater plant production soon after monsoon sets in which resulted in increased litter quantity (Edward and Bohlen, 1996; Edward *et al*., 1995).

The observations on response of NPK in different sites and plantations indicate the specific effect of inorganic fertilizers on earthworm population. Since

Eutyphoeus sp. living in deep soil is not affected immediately by fertilizer application, but the density of epigeic species *P. excavatus* was significantly affected.

In ML plantation site of both SKT and PUC, no significant variation of earthworms between control and fertilizer treated area may be related to short duration of the maize plantation.

The results of One-Way ANOVA in control and fertilized treated area have shown a significant variation ($P < 0.05$) between juvenile populations of 0 - 10 cm depth in PCL plantation of SKT. It may be attributed to positive influence of fertilizer. A significant variation ($P < 0.05$) observed in immature population in PCL plantation of SKT between the controls and treated at 10 - 20 cm depth may be related to the functional group of earthworms. Anecic worms like *M. houletti* and *Drawida sp.* may pull the surface litter into subsurface obtaining sufficient amount of food supply. Adult worm shows more significant variations at 0 – 10 cm and 10 - 20 cm depth ($P < 0.05$ and $P < 0.01$ respectively). These significant variations in SKT provide evidence that inorganic chemical fertilizer influence earthworm population.

Unlike SKT, PUC shows a significant variation ($P < 0.01$) among juvenile population at 10 - 20 cm depth in PCL plantation, and the immature population shows variation at 0 - 10 cm and 20 - 30 cm depth by $P < 0.05$ and $P < 0.01$ respectively. But, adult populations are not significantly affected by fertilizer at all three strata. This may be attributed to possible resistance of adult worms to fertilizer treatment.

Studies have shown that use of inorganic fertilizer in a moderate dose increased earthworm population. Some researchers suggest the use of chemical and organic fertilizer in a judicious manner (Reddy and Ground, 1987). While others researchers suggest the use of organic manure (Curry, 1976; Edwards and Lofty, 1982b; Lofs-Holmin, 1983a; Timmerman *et al.,* 2006).

Summary

This pioneering research on the study of earthworm population ecology of Mizoram was carried out during June 2002 to December 2004. Mizoram, having an area of 21,081 sq. km, lies between 21°56' N and 24°31'N latitude and 92°16' E and 93°26'E longitude. The State of Mizoram, located in the north eastern corner of India, is sandwiched between Chittagong Hill Tracts of Bangladesh (in the west) and Chin Hills of Myanmar (in the east and south) and is bounded in the north by the states like Tripura, Assam and Manipur. The average temperature varies between 11^oC and 21^oC in winter and climbs up to 20^oC and 32^oC in summer months. The monsoon season stretches from mid May to mid October. The annual rainfall is about 250 mm.

Importance of earthworms in maintaining soil fertility is known from ancient time. Reports on the studies of earthworms are available in plenty from temperate, tropical and sub-tropical regions of the world. But only sporadic reports are available on studies of earthworm from north east India. Prior to the present investigation no comprehensive work has been carried on studies of earthworm in Mizoram. Therefore, considering the lack of systematic studies on earthworm population ecology and its influence on soil nutrient levels under mixed cropping, plantations in general and agroforestry systems in particular, the present study entitled "Ecological studies on earthworm population in agroforestry system of Mizoram" was designed with the following objectives:

(a) to study the earthworm species diversity, distribution and population in different farming system,

(b) to quantify the earthworm communities in terms of its abundance in different farming system,

(c) to study in depth the ecology of earthworm population in agroforestry system (experimental plots) considering the following aspects –

(i) influence of the level of soil nutrients on the distribution and density of earthworm population.

(ii) total biomass and secondary production of earthworm population

(iii) worm cast production and its nutrient status in relation to adjacent soil.

(iv) effect of fertilizers (N, P & K) on earthworm population dynamics and abundance.

Two agroforestry experimental plots were laid at Sakawrtuichhun (SKT) village area and within Pachhunga University College campus (PUC) for experimental sites. Same treatments were given in each experimental site. The treatments were Pine apple + Citrus + *Leucaena leucocephala* (hedge species) – control and Pine apple + Citrus + *Leucaena leucocephala* (NPK g/plant in the ratio of 12.2 : 12.2 : 12.0) in PCL plantations and Maize + *Leucaena leucocephala* - control and Maize + *Leucaena leucocephala* (NPK kg/ha in the ratio of 60 : 40 : 40) in ML plantations. Climatic conditions were more or less same in the two study sites. However, PUC had a higher slope percentage and is at a higher elevation by about 175 m. The soil of SKT is sandy clay loam while PUC has a clayey loam soil.

Four species of earthworms were common to both sites, and *Perionyx macintoshi* is found in PUC. The analysis of species diversity from mixed cropping, agroforestry and plantation sites of four districts of the State including experimental plots 'SKT' and 'PUC' contributed eleven more species to the existing one species - *E. gigas* reported by Julka. One new species of earthworm *Eutyphoeus mizoramensis* sp. nov. was discovered during the course of study. *E. mizoramensis* sp. nov. is closely related to *E. manipurensis manipurensis* Stephenson and *E. hastatus* Gates. The identified earthworm species fall under three families viz. Megascolecidae, Octochaetidae and Moniligastridae. The identified earthworms are :-

1. *Amynthas alexandri* Beddard (Megascolecidae family)
2. *Amynthas cortices* Kinberg (Megascolecidae family)
3. *Drawida sp.* (Moniligastridae family)
4. *Drawida nagana* Gates (Moniligastridae family)
5. *Drawida nepalensis* Michaelsen (Moniligastridae family)
6. *Drawida rangamatiana* Stephenson (Moniligastridae family)
7. *Eutyphoeus assamensis* Stephenson (Octochaetidae family)
8. *Eutyphoeus gigas* Stephenson (Octochaetidae family)
9. *Eutyphoeus mizoramensis* sp. nov. (Octochaetidae family)
10. *Metaphire houletti* Perrier (Megascolecidae family)
11. *Perionyx excavatus* Perrier (Megascolecidae family)
12. *Perionyx macintoshi* Perrier (Megascolecidae family)

All three morpho-ecological categories of earthworms (epigeic, anecic and endogeic) were found in the present study. Aizawl district harbours all twelve reported earthworm species. Five species (*Drawida sp., Eutyphoeus gigas, E. mizoramensis sp. nov., Perionyx excavatus* and *P. macintoshi*) were found in Mamit district, four species (*Drawida sp., Eutyphoeus gigas, E. mizoramensis sp. nov.* and *Perionyx excavatus*) in Kolasib district and 2 species (*Drawida sp.,* and *Perionyx excavatus*) in Champhai district. *Perionyx excavatus* and *Drawida sp.* were most versatile in distribution, found in all four districts. Endogeic species (*Eutyphoeus sp.*) were not found in Teak plantation, Distribution of *E. assamensis* was restricted to Tlangnuam mixed plantation.

Among all thirteen sites studied, Tlangnuam mixed plantation had highest earthworm diversity with eight species (*Amynthas alexandri, A. cortices, Drawida nepalensis, D. rangamatiana, Eutyphoeus assamensis, E. gigas, Perionyx excavatus* and *P. macintoshi*) followed by seven species each in Teak plantation (*Amynthas alexandri, Drawida sp., D. nagana, D. nepalensis, D. rangamatiana, Metaphire houletti, Perionyx excavatus)* and Orange plantation (*A. cortices, Drawida sp., D. nepalensis, D. rangamatiana, Eutyphoeus mizoramensis sp nov., Metaphire houletti, Perionyx excavatus*). The overall soil nutrient content and worm cast production rate among different study sites was found to be highest at Tlangnuam mixed plantation. Highest population density was recorded in Teak plantation and lowest density in Banana plantation which was often disturbed. Among different land use practices, mixed plantations had highest earthworm diversity, followed by Orchards, Teak plantation and Jhumed cultivation. Farming operation like weeding is found to have negative effects on earthworm population density and biomass. Experimental site PUC had higher earthworm diversity with five species (*Drawida sp., Eutyphoeus mizoramensis* *sp. nov., Metaphire houletti, Perionyx excavatus* and *P. macintoshi*) than SKT which has four species (*Drawida sp., Eutyphoeus mizoramensis sp. nov., Metaphire houletti* and *Perionyx excavatus*) of earthworms.

Earthworm population density and biomass were higher in SKT compared to PUC. Highest record of density in both experimental sites was in the first year of study. Peak biomass was observed in September 2003 and October 2002 in SKT and PUC respectively. The biomass was greatly reduced in the third year of study. Strata-wise density and biomass (vertical distribution) followed similar pattern (0-10 cm > 10-20 cm > 20-30 cm depth). Density decreased with increasing depth except in hot summer months (March to May) where the second stratum harbored highest population density. Species-wise density study showed that *Drawida sp.* had highest density throughout the year in both SKT and PUC. Age-wise study revealed that adult population greatly decreased in the third year. Juvenile and immature worms are more just after the monsoon sets in, while adults were usually more in post rainy period. Immature and Juvenile worms are concentrated in the upper most strata (0-10 cm).

The total density and biomass of earthworm population were higher in rainy months when both moisture content and temperature of soil were in relatively high range. Rainfall showed significant correlated at $P<0.01$ with earthworm density and biomass. Soil physical factors like temperature and moisture content showed a significant correlation with earthworm density at $P<0.01$, but biomass showed significant correlation with moisture content only ($P<0.01$).

Seasonal variation of soil chemical components like pH, OC, N, P and K showed a similar pattern in the two experimental sites. SKT had a higher nutrient component compared to PUC. OC and P showed a significant correlation with earthworm density at P<0.05 and P<0.01 respectively in SKT. Whereas in PUC, pH and C/N ratio are significantly correlated with density at P<0.05 and P<0.01 respectively. A negative significant correlation between N and density was observed in PUC. Among different chemical components, earthworm biomass showed significant correlation with potassium in SKT only.

Secondary production of earthworms was relatively higher in the fist two years of study and greatly decreased by the third year. Strata-wise calculation had shown that 0 - 10 cm depth contributes about 60% of the total production. 30% and 10% were contributed by 10 - 20 cm and 20 - 30 cm depth respectively.

Worm cast production was higher in SKT compared to PUC. Casts were found only in the month of August in the third year of study in PUC. Student t-test showed a significant difference (mostly at P<0.01) in the moisture content and chemical components between worm cast and its adjacent soil with the exception of N which shows significant difference at P<0.05 in PUC (2002).

Application of inorganic fertilizer was found to have a positive influence on earthworm population density and biomass in both PCL and ML plantations of SKT and PUC. The population turnover (Maximum population : minimum population) in control and NPK treated indicated greater population fluctuation in control in both SKT and PUC.

One-Way Analysis of variance (ANOVA) showed a significant variation in Juvenile population between control and NPK treatment at 0 - 10 cm ($P < 0.05$) and 10 - 20 cm depth ($P < 0.01$). Immature population shows a significant variation at 0 - 10 cm ($P < 0.05$), 10 - 20 cm depth ($P < 0.05$) and 20 - 30 cm ($P < 0.01$). Significant variation in adult populations between Control and NPK treatment were observed at 0 - 10 cm and 10 - 20 cm depth at $P < 0.05$ and $P < 0.01$ levels respectively in the two experimental sites. Epigeic species of earthworms showed significant variation between control and fertilizer treated area.

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- *cross reference*

BIO-DATA

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Educational qualifications

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HSLC	1990	MBSE	II	57.47
P.U. (Sc.)	1994	NEHU	II	57.22
B.Sc. (Zoology)	1997	NEHU	II	57.62
M.Sc. (Zoology)	1999	NEHU	I	62.67

Research experience

Worked as JRF and SRF in the research project sanctioned by ICAR, New Delhi for three years (2002, June – 2005, May).

Workshop/Seminar attended

1. Workshop on Development of Vanaspati Van in Mizoram. 14th - 15th February 2002 held at Aizawl, organised by Mizoram Vanaspati Van Society & Department of Forestry, MZU. Aizawl.
2. Regional Seminar on Biodiversity of the North East. 23rd – 24th November 2002 held at Aizawl, organized by Department of forestry, Mizoram

University in collaboration with Humbold Club, Max Muller Bhahan, Kolkatta.

3. National Seminar on Recent advances and Rebuilding of Fish and Fisheries in North East India during 22nd - 23rd August 2007 held at St. Anthony's College, Shillong.

Research Publications

i. Julka, J.M., Ramanujam, S.N. and **Lalthanzara, H.** 2005. On a new species of earthworm genus *Eutyphoeus* (Octochaetidae: Oligochaeta) from Mizoram, India. *Megadrilogica* **10**(9): 69-72.

ii. Ramanujam, S.N., **Lalthanzara, H.** and Jha, L.K. 2004. Biodiversity of earthworms in Mizoram. *J. Natcon* **16**(1): 129-134.

iii. Ramanujam, S.N., **Lalthanzara, H.** and Jha, L.K. 2004. 2004. Effect of Soil and Vegetation on the Distribution of earthworms in and around Aizawl, Mizoram, India. *Sci vis.* **4**(1): 23-28.