ECOLOGICAL SIGNIFICANCE OF MICRO-ARTHROPODS IN FOREST AND JHUMLAND ECOSYSTEM OF MOKOKCHUNG DISTRICT,NAGALAND.

THESIS SUBMITTED TO NAGALAND UNIVERSITY IN FULFILLMENT OF THE REQUIREMENTS FOR AWARD OF
DOCTOR OF PHILOSOPHY IN ZOOLOGY.

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DECLARATION

I, Mr. Kruolalie Tsurho, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form the basis of award of any previous degree to me, 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 University/Institute.

This is being submitted to Nagaland University for the degree of Doctor of Philosophy in Zoology.

Sd/-
(KRUOLALIE TSURHO)
Candidate

CERTIFICATE

This is to certify that the thesis entitled **"Ecological significance of microarthropods in Forest and Jhumland ecosystem of Mokokchung District, Nagaland",** submitted to Nagaland University in fulfilment of the requirements for the degree of Doctor of Philosophy in Zoology, is an original research work carried out by Mr. Kruolalie Tsurho, Registration No. 256/2006 under my supervision and guidance.

Further certified that no part of this thesis has been submitted anywhere for any other research degree.

Place:

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Supervisor

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The state of Nagaland lies in the bio-geographic tri-junction of the Indian, the Himalaya and the oriental landmasses. The state is rich in biodiversity and it owes this treasure to the geo-climatic conditions which is a gift from nature. This region is also a centre of gene diversity of domesticated crops and a secondary centre for several economically important plants and animal species.

That the state of Nagaland offers varied climatic regimes, is evident from the types of vegetation – *tropical rain forests* in the lowlands bordering Assam, *sub-tropical forests* in the majority of the state and *temperate forests* in the Saramati, Phek regions *etc*. This variation naturally leads to differences in the distribution of animal species in the different areas. In addition, the altitudinal variations of the different areas play a major role in the distribution of the animals. The rich and diverse fauna also includes some endemic species like the Blythe's Tragopan.

But the rich biodiversity is slowly declining due to random destruction of the forest ecosystem and also *slash and burn* during jhum cultivation which is destroying the habitat of the soil microarthropods. This is not limited to Nagaland, but is a worldwide phenomenon, wherein, worldwide, tropical forests are disappearing at an alarming rate (Laurance, 1999). This loss and fragmentation of tropical forests appears to be the single greatest threat to the world's biological diversity (Whitmore, 1990). Aforestation may be a solution, but conversion of natural forest to plantation forest may lead to a change in litter quality, composition and hence microbial and faunal decomposer assemblages (Ananthakrishnan, 1996).

Therefore, it is important to understand the changes in key ecosystem processes such as decomposition and nutrient cycling that are encountered when converting natural forest or other land uses into plantation forests, or when rehabilitating natural forest for a sustainable management of tropical forests (Attignon *et al*., 2004).

The term “soil animals” refers to organisms inhabiting this niche or habitat. According to some authors like Wallwork (1970), these organisms must spend at least a part of their respective life cycles in the soil so as to be qualified to be termed as a soil organism (also termed as edaphon). They in turn, influence the habitat that they live in and this ultimately influences the flora and fauna in that area. Among the soil fauna, arthropods constitute a very diverse group, inhabiting different soil types.

Soil invertebrates are important components of tropical ecosystems. This diverse group of animals covers a range of taxa, the most important being protozoans, nematodes, earthworms, mites (Acarina), springtails (Collembola), millipedes, centipedes and range of insects (mostly belonging to Diptera, Coleoptera and Isoptera). Soil invertebrates perform important functions related to the growth conditions of plants. For example, ecosystem engineers such as termites and earthworms increase soil porosity and average pore size by tunnelling through the soil (Edwards and Shipitalo, 1998). These invertebrates ingest considerable amounts of soil and dead plant material, thereby contributing to the mixing of organic matter and mineral soil. This improves aggregate stability and increases the surface of organic material so that it is more readily colonised and decomposed by soil bacteria and fungi (Lavelle *et al.*, 1997). Examples have shown that soil fauna enhance nitrogen mineralization markedly by up to 25% (Seastedt, 1984; Verhoef and Brussard, 1990).

Soil invertebrates are the dominant animal group in many terrestrial ecosystems, and may have higher biomass on an area basis than above-ground herbivorous insects or vertebrates (Odum, 1971). Soil invertebrates represent, with their relatively high protein content, a significant pool of nutrients such as nitrogen, which may ultimately become available for primary production. Soil invertebrates are also important players in terrestrial food webs. They are an important food source for many predacious invertebrates and vertebrates (Bilde *et al.*, 2000; McNabb *et al.*, 2001).

Soil macro fauna make an ideal focus for the study of the effects of disturbance in fragmented habitats because they are an important component of native ecosystems, sensitive to changes in the habitat, and easily sampled in large numbers (Bromham *et al*., 1999). In recent times the study of soil arthropods has been recognized as an area of particular concern because they are ubiquitous, abundant, diverse and ecologically important, and also helps in understanding the pattern of distribution as well as their roles in ecosystem processes.

In studying the invertebrate community two aspects must be taken into consideration *i.e*., (i) size and abundance of components and (ii) ground invertebrate. This is important due to the diversity and abundance of the faunal component, which, according to Peterson & Luxton (1982) are divided into microfauna, mesofauna, and macrofauna, and the function of each group in the decomposition process is quite differentiated. Moreover, some ecological processes are dependent on the size of the animal at general scale of time and space, and size may have an overriding effect on ecological relationship (Wikars & Schimmel, 2001). This is especially important for collembola and Acari groups in which the mean size is so small that individuals can find refuge in soil interstices, and which may not be subjected to predation by larger predators even when they occur in the litter layer. The numerical dominance of certain invertebrate groups can result in opposite patterns of response to environmental factors and the habitat (Bromham *et al*., 1999).

Secondly, the ground or soil invertebrates form an abundant and diverse component, fulfilling a variety of ecological roles (Abbott *et al.*, 1980), and contribute to the process of organic matter decomposition, thus enriching the soil with labile materials necessary for plant growth *etc* (Aber and Melillo, 1980; Berg and Staaf, 1980). According to Swift (1976), Palm and Sanchez (1991), Heal *et al* (1997) *etc*., the decomposition and nutrient release patterns of organic materials are determined by the organic constituents and nutrient content of the material, the decomposer organisms present, and the environmental conditions.

Weathering and the action of soil organisms are the two main agents involved in formation of soil on Earth. Furthermore, soil can be generally divided into surface soil, sub-soil *etc*. There are different types of rocks and therefore their weathering and disintegration results in different types of minerals and soils. These particles are interwoven in a short of meshwork, with air and water films – and this supports the soil microorganisms (Technical bulletin No. 3, ICAR, 2001).

Microarthropods have been classified based mainly on size (100 µm to a few millimeters). According to Price (1973), soil microarthropods are those present in the soil and overlying layer of organic debris, and which have a body length of less than 2 or 3 mm. They include the Acarina (mites), Collembola, Symphyla, Protura, Diplura, Pauropoda, small centipedes and millipedes, small beetles, Proturan and small insects from several orders. Amongst these, the Acarina and Collembolan constitute 72-97% of the total arthropod fauna of Indian soil (Singh & Mukherji, 1973; Singh & Pillai, 1975; Roy *et al*, 1998).

Collembolans are wingless insects or apterygotes, which can be placed under three sub-groups *viz*. Entomorbryomorpha, Poduromorpha and Symphypleona. They are largely detritus or fungal feeders - most of them feeding on decaying vegetation, bacteria, fungi, algae, pollen and other forms of organic material and have well developed mouthparts capable of fragmenting plant material (Seastedt, 1984). They play an important role in the decomposition process (Christensen & Bellinger, 1980), and are good indicators of soil quality *via* their relationship with minerals/chemicals like Na, K and N of soil (Hagvar, 1984).

Acarina forms an order under the class Arachnida. They are divided into four sub orders *viz* (i) Cryptostigmata (oribatid), (ii) Mesostigmata (Gamasida), (iii) Prostigmata (Actinediad), and (iv) Astigmata. The Cryptostigmata are also called beetle mites for resembling small beetles, and are found in leaf litter, under bark and stones. The Mesostigmata are generally flatened, tick like mites, and they are found as predaceous, scavengers or in

parasitic form on leaf litter, humus and soil. Prostigmata are delicate, white to colourless and subject to desiccation some are free living occurring in litter, moss or water and vary in food habits. Astigmata are free living and are commonly called cheese mites having no stigma or trachea. They are seen associated with highly organic, decomposing material such as manure. Appreciable work on their classification has been done by Bhandari & Somani (1994).

Microarthropods are believed to play a significant role in accelerating plant residue decomposition, accelerating the flow of energy and nutrients through the soil, through their interactions with microflora and causing increased rates of microbial biomass turnover (Seastedt, 1984; Norton, 1985; Moore *et al.*, 1988). But (Norton, 1985) is of the opinion that their effect on decomposition through fragmentation and comminucation may not be so significant since they ingest only approximately 2% of the annual plant residue production.

But the inescapable fact is their undeniable importance in soil fertility. Therefore, the factors leading to their abundance is a pre-requisite for sustainablility of the ecosystem. According to Wallwork (1976), the main factors determining the abundance of soil microarthropods include the type and quantity of decomposing organic residue and its effect on the microfloral population, the structural stability of the soil and resulting porosity or the soil water regime.

Population and species composition of soil microarthropods are influenced by soil profiles along with physical and chemical factors such as light, temperature and moisture at an optimum condition. For instance, moisture can be considered as a limiting factor because moisture is dependent on rainfall, and a majority of the soil fauna prefers conditions that are neither too dry nor wet. Similarly, temperature has an equally important role. Horizontal variations in temperature are determined to large extent by the structural feature of vegetation (Wallwork, 1976). Moreover a seasonal response to temperature changes is shown by soil fauna in their pattern of

vertical distribution in the soil (Aitchison, 1979 a, b, c). Similarly, Merriam *et al*. (1983) opined that humidity and light intensity play significant roles on microarthropod activity.

Soil rich in organic matter are generally rich in nutrients, greater water holding capacity, nitrogen, phosphorus and sulphur, and their decomposition by microorganisms takes place in the soil and it makes conditions highly favourable for fungi which are the source of food for various soil microarthropods (Mukharji & Singh, 1970; Banerjee, 1976; Sharon *et al.*, 2001).

Apart from this, various biotic and abiotic factors of the soil have profound influences on distribution of soil fauna. For example, the biotic components in forest soil are vegetation or leaf litter, which exerts an enormous amount of influence on soil fauna (Haq & Ramani, 1991). Their decomposition proceeds along a series of successional stages, and ending in finely particulate humus materials which becomes available at greater depths in the soil profile due to leaching and animal activity, and act as substrate and food for microorganisms and soil animals. Thus a greater number of soil animals are concentrated where there is more decomposition of organic materials. However, Anderson (1971) reported that seasonal fluctuation and movement of some species do occur along the soil profile, but the population density in a particular horizon remains constant for many species throughout the year.

Different workers like Gill (1969), Anderson (1971), Price (1973), Marshal (1974), Usher (1975), Edberg & Hagvar (1999), Detsis (2000) *etc* have studied the phenomenon of vertical distribution of soil microarthropods under different environmental gradients, and in general they have found that Cryptostigmata are found mostly in the litter, Prostigmata, are found in deep layer of the soil (because of their predatory habit), mites as a whole are observed to migrate to deeper soil layer during hot, dry and winter season, large sized Collembolan species appear on the surface, while smaller sized are found to be in humus layers of the soil.

According to Ananthakhrishnan *et al.* (1992, 1993), the heterogeneity of organic profile and the diversity of microhabitats encourage a spatial separation of species population and thereby reduce inter-specific competition. This increases species diversity, which is again enhanced by two factors *i.e.* (i) the various organic horizons provide different ranges of substrate on which soil animals can feed, and (ii) there is a decrease in the particle size of the organic material with depth from the litter to the humus. This means that there is progressive reduction in the size of the soil spaces and the living space available to non-burrowing soil animals.

Another aspect is the effect of fire (slash and burn for jhum cultivation). It is known that soil is a good insulator against heat, and therefore does protect soil organisms from the heat of a fire, but mineral soil temperatures can, and do rise during a fire and the litter layer, where many organisms live, is often destroyed. Raison (1979), precisely describing how a fire burns in forest conditions - "in small fires with flames about l m high, soil temperatures at 2.5 cm depth increased by 20° C to reach 40° C 15 min after the fire had passed. Temperatures had fallen to 25°C 45 min later". The heat from a fire does not penetrate very deeply into the mineral soil, but it does penetrate into the top few centimetres - the litter layer, and the top 5 cm of mineral soil where the soil biotic community is most active. It is likely that the deeper soil arthropods will be relatively unaffected; however, arthropods on the litter layer and on the surface of the mineral soils will experience significantly elevated temperatures. The elevated temperatures (which may also lower relative humidity) pose a real problem to the arthropods below the ground.

According to Villani *et al*. (1999), in general, above-ground soil arthropods have well-developed lipid layers in the cuticle, and are thus adapted to a habitat with relatively constant temperature and humidity (but they may be combusted when fire rages beyond a certain temperature). These characters are reduced or lacking in many below-ground arthropods, and so, may be very sensitive to even small amounts of soil heating. According to Ahlgren & Ahlgren (1965); Buffington, (1967); Abbott, (1984); Borchers &

Perry, (1990); Shaw, (1997) *etc*., soil microarthropod and insect populations are, as a matter of fact, almost always reduced by fire.

But Springett (1971) found that populations of microarthropods in general were not reduced by fire, but populations of fungivorous mites were. However, the sampling was done three years after the burning and therefore, the microarthropod populations had probably rebounded. Additionally, even if fire does not directly reduce oribatid numbers, it might reduce their fungal food source, and influence the heterogeneity.

Fires often shift the microbial community toward bacterial, rather than fungal dominance. The nanorchestid mites (which are abundant in heavily burned soils), for example, might be feeding on soil algae that appeared on the soil surface shortly after the fire (Schuster & Schuster, 1977). Similarly, El-Abayad & Webster (1968) found that many ascomycetes fruit prolifically after a fire. Thus, fire's effects on the soil biotic community are likely to be both direct and indirect.

We, therefore, need to know more about the natural history and ecosystem functions of individual microarthropod and fungal species. This functional information may help in interpreting data about what is happening to the soil community after a fire and whether the impacts on the soil community will seriously impact soil processes, including decomposition and mineralization and perhaps even assess fire's impacts on the soil's resistance to pathogenic fungi. It will also help to judge whether microarthropod populations are simply reduced by fire or whether they also respond positively or negatively to post-fire conditions.

The present investigation aims to fill the gaps in knowledge, especially with regards to Nagaland, where, the age-old practice of jhum cultivation or slash-and-burn system of clearing of fallow is still practiced. Except for study on soil arthropod communities with reference to Jhum agro-ecosystem by Ao (1987), and Duolo (2007) on soil microarthropod population dynamics, no other information is available on different aspects of soil microarthropods.

A review of literature shows that much work has been done on microarthropods. They are recognized as an important part in the development of soil. The relative abundance of microarthropods have been studied by many workers, for example, Luxton (1983) found out that amongst the microarthropod population in pasture soils on Kaipaki peat (New Zealand), the highest relative abundance was seen in Cryptostigmata followed by Mesostigmata, Prostigmata and Astigmata. Their great diversity has been studied by Norton (1990), who found that Orabitids are among the most numerically dominant soil microarthropod groups. Similarly, Sengupta & Sanyal (1991) have shown that Acarina dominate amongst the Collembola in terms of number and species in a comparative study on soil microarthropods fauna in paddy field and control plot in West Bengal, India. Roy *et al.* (1998) studied soil arthropods inhabiting grassland and silvipastoral systems and reported higher species diversity in grassland. A comparative study on the Oribatid (mites) communities in two different soil types in a cool temperate forest in Japan was made by Kaneko (1985). Anderson (1978) studied on inter and intra habitat relationship between woodland Cryptostigmata species diversity and diversity of soil and litter microhabitats. Petersen (1980), while investigating the vertical distribution of nine selected species in beach forest ecosystem in Denmark, had observed that all the species confined to the litter and the upper most 6cm of the mineral layer. Similarly, Willard (1973) studied population and biomass of soil arthropods in Canada and reported that population of Collembola was more common in 0-10cm soil layers.

Regulation of microbial populations by microarthropods have been worked on by Lavelle *et al.* (1993), Heneghan *et al*. (1999), *etc*. who found that the degree of regulation is site-specific *i.e*., stronger or more pronounced in humid tropical forests than temperate regions. That microarthropod density is dependent on climatic regimes has been worked on by many authors like Van Gestel and Van Diepen (1997); Choi *et al*. (2002); Cassagne *et al*. (2003) *etc*. who opined that they are likely to have both direct and indirect impacts on soil systems. Similarly, Narula *et al.* (1998) studied Collembola and mites of deciduous forest stand in Kurukshetra, India, and reported that soil moisture and temperature collectively regulate the population.

Chakraborti & Bhattacharya (1996) studied soil microarthropods in a rubber plantation and an adjacent wasteland exhibiting peaks in early monsoon and post monsoon. Metz (1971) studied on vertical movement of Acarina under moisture regime and found decrease in oribatid numbers in lower soil layer. The effect of temperature and moisture fluctuations on experimental soil microarthropods community has also been studied by Huhta & Hanninen (2001). Kaczmarek (1975) found maximum population of Collembola in the monsoon months when the moisture level reached its peak and minimum in summer months when the moisture content was significantly low. Wood (1971) also observed decreased population of microarthropodss with the increase in seasonal and regional aridity.

The role of microarthropods in decomposition and mineralization has been worked on by Seastedt (1984), Hunt *et al*. (1987), Hunter *et al.* (2003). In this respect Curry (1978) studied on the relationship between microarthropods communities and soil and vegetation type. Similarly, Gonzalez & Seastedt (2000) studied on soil fauna and plant litter decomposition in tropical and sub-alpine forests and indicated that soil fauna have a disproportionately larger effect on litter decomposition in a tropical wet forest than in a tropical dry or a sub-alpine forest. Soil microarthropods also affect decomposition processes directly through fragmentation of litter and through fecal production (Seastedt, 1984; Sackett *et al*., 2010). Hence, a better understanding of effects of climate changes on the abundance and community structure of soil microarthropods can aid predictions of how soil ecosystemsmay function under future climatic conditions.

Climate changes can influence soil microarthropod community abundance and composition directly by altering soil microclimate and indirectly by altering resource availability and the composition of the soil food web. Warming and changes in precipitation amounts, for example, can directly alter soil temperature and moisture, factors that strongly influence microarthropod reproduction and development rates (Van Straalen, 1994; Uvarov, 2003). In fact, soil microarthropods are extremely responsive to

changes in soil moisture, a pattern seen in numerous studies across diverse ecosystems (Lindberg *et al*., 2002; Moron-Rios *et al*., 2010).

Unlike soil moisture, warming impacts on microarthropods have been context-dependent, and abundance responses varied across experiments (Coulson *et al*., 1996; Huhta and Hänninen, 2001; Hågvar and Klanderud, 2009). Usher (1975) revealed that temporal variation in microarthropods abundance was attributable to factors such as temperature, precipitation and litter fall. Work by Sjursen *et al*. (2005) suggested that warming may indirectly alter soil microarthropod communities by causing a shift in the abundance and composition of soil organisms upon which they prey. In addition, temperature and other climate factors may indirectly influence soil microarthropod communities through changes in plant physiology or community structure which can alter resource availability and microhabitat conditions (Cotrufo and Ineson, 1995; Kardol *et al*., 2010b). The role of human interference with regard to soil fertility or nutrient content was studied by Zhong & Quiguo (2001), who concluded that soil organic carbon concentration changed with land cover and was subject to human disturbances.

In the North Eastern part of India, studies on soil microarthropods have also been carried out by many workers. For example, Reddy & Alfred (1989) reported on microarthropods associated in the decomposition process of needle litter of pine forest in Meghalaya; Darlong & Alfred (1982) on the differences in arthropods population structure in soils of forest and Jhum sites of North Eastern India; Darlong & Alfred (1984) on the seasonal population dynamics of dominant Collembola species in a pine forest and Jhum soils of Meghalaya; Paul & Alfred (1986) on comparative study of soil microarthropods in three disturbed habitats of Meghalaya; Hattar *et al.* (1992) on comparative study on soil Acarina and Collembola in the pine forest and cultivated land of Khasi Hill, Meghalaya, and found higher number of species in pine forest; Thingbaijam *et al.* (1986) on the population density of soil arthropods in subtropical forest ecosystems at Shiroy Hill, Manipur; Reddy & Alfred (1989) on seasonal abundance of microarthropods of needle-litter during decomposition in a pine plantation in relation to litter mass-loss,

moisture and temperature; Chakraborti & Bhattacharya (1991) on influence of Human activities on soil Oribatid community of a rubber plantation and an adjacent wasteland in Tripura.

Yadava & Singh (1988) observed maximum population density of soil microarthropods during rainy season and minimum during dry winter season in their study at Oak forest of Shiroy Hill, Manipur. Singh & Yadava (1998) studied on seasonal fluctuation of Oribatid mites in sub-tropical forest ecosystem of Manipur, India and reported maximum population during summer with declining trend towards the winter season. Singh *et al.* (1995) observed higher value of organic carbon in natural forest than bamboo forest and Jhum fallow.

Location

The present study was carried out in two adjacent areas of forest and jhumland ecosystems in *Mopungchuket* village and *Chuchuyimpang* village respectively, under Mokokchung district, Nagaland, which lies at 26^{o} 11' 36" North latitude and in between 94^{o} 17' 44" to 94^{o} 45' 42'' (E) longitude (Photoplate nos. l -3).

The forest site (Photoplate nos. 4 - 5) comprises of rich vegetation which have not been disturbed for more than twenty years. The jhumland area (Photoplate nos. 6 - 8) has comparatively thin vegetation due to frequent clearance for jhum cultivation. The jhum cycle is approximately 8 - 10 years.

Vegetation

The vertical stratification in the natural forest is very distinct. The canopy layers have an average height of 20 meters or more. Emergent trees that overshoot the canopy layers are not present. The small trees, shrubs and herbs compose the rest of the under- canopy layer which was dense in some places. The dominant trees species that form the canopy layer are *Albizia procera, Schima wallichii, Alnus nepalensis, Castinopsis indica, Lithocarpus elegans, Michellia champaca* and *Persia villosa*. The smaller trees mostly belong to the families of Lauraceae, Euphobiaceae, Araliaceae, Ficaseae and Rubiaceae. The average height of these members is found to be 5 to 15 mts. The ground flora is rich and also epiphytes, climbers and lianas are also found to be growing abundantly.

The jhum area is not well stratified as the natural forest. The tree species present are the species that were left uncut while clearing the forest and the stumps that survived jhum cultivation. *Quercus serrata, Erythrina striata, Albizia procera, Schima walichii* are the dominant species present in the jhum areas.

Climate

The climate of the area is monsoon type with warm moist summers and cool dry winters. The meteorological data based on three years (2009 - 2011) (Table 1- 3) indicates the climatic condition in Nagaland which reveals that June to October constitute wet months and November to May as dry months. The dry period can be further divided into summer (March to May) and cool dry season (November to February). Thus there is distinct summer (March to May), rainy (June to October) and winter (November to February) seasons. March constitute the transitional month between winter and summer whereas October is the transitional month between rainy and winter season.

Meteorological data during the study period

The graphical representation of meteorological data during the study period (January to December, 2009 - 2011) is shown in tables 1-3 and figures 1-3. The average maximum and minimum air temperature in 2009 was recorded in the month of July and August (20.4°C) and January (8.5°C) respectively. The maximum annual rainfall during the study period was recorded in the month of August (324 cm) and minimum in the month of March (3.7 cm). The total annual rainfall was 1741.5 cm. The maximum relative humidity was recorded in the month of September (85 %) and minimum in the month of March (62 %).

The average maximum and minimum air temperature in 2010 was recorded in the month of August (21.9°C) and January (6.3°C) respectively. The maximum annual rainfall during the study period was recorded in the month of July (421 cm) and minimum in the month of March (14.8 cm). The total annual rainfall was 1617.3 cm. The maximum relative humidity was recorded in the month of June and August (82 %) and minimum in the month of November (66 %).

The average maximum and minimum air temperature in 2011 was recorded in the month of July (20.5°C) and January (9.6°C) respectively. The

maximum annual rainfall during the study period was recorded in the month of July (972.5 cm) and minimum in the month of November (15.3 cm). The total annual rainfall was 2221 cm. No rainfall was recorded for the month of December, January and February. The maximum relative humidity was recorded in the month of July (83 %) and minimum in the month of December (35.5 %).

Table 1. Meteorological data for 2009

Items	Months											
	Jan	**Feb**	**Mar**	**Ap**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Av.Min Temp(°C)	8.5	9.6	13	15.6	19.2	19.7	20.4	20.4	19.4	17.1	13.3	11.8
Rainfall (mm)	5.5	11.7	3.7	76.2	171.1	287.6	292.4	324	306.3	88.8	29.1	6.7
Av.R.H %	69	73	62	74	75	82	82	85	80	78	71	68
No. of rainy days	6	11	4	12	16	20	22	23	21	12	7	2

Table 2. Meteorological data for 2010

Items	Months											
	Jan	**Feb**	**Mar**	**Ap**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Av.Min Temp(°C)	6.3	8.6	13.6	15.9	18	19.7	20.1	21.9	20.3	16.6	12.5	10.3
Rainfall (mm)	18.1	14.8	70.3	68.3	187	341.8	421.4	235.8	158.8	101	Nil	Nil
Av.R.H %	70	67	67	72	78	82	81	82	79	76	66	72
No. of rainy days	4	4	10	11	19	21	24	22	16	10	Nil	Nil

Table 3. Meteorological data for 2011

Items	Months											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Av.Min Temp(°C)	9.6	11.8	14.4	16.6	18.3	19.9	20.5	20.4	19.7	16.8	12.8	10.2
Rainfall (mm)	Nil	Nil	37.9	117.5	81.4	233.1	972.5	320.3	145	298	15.3	Nil
Av.R.H%	67	59	53	70	76	78	83	82	78	77	73	35.5
No. of rainy days	Nil	Nil	5	12	11	18	6	21	17	13	3	Nil

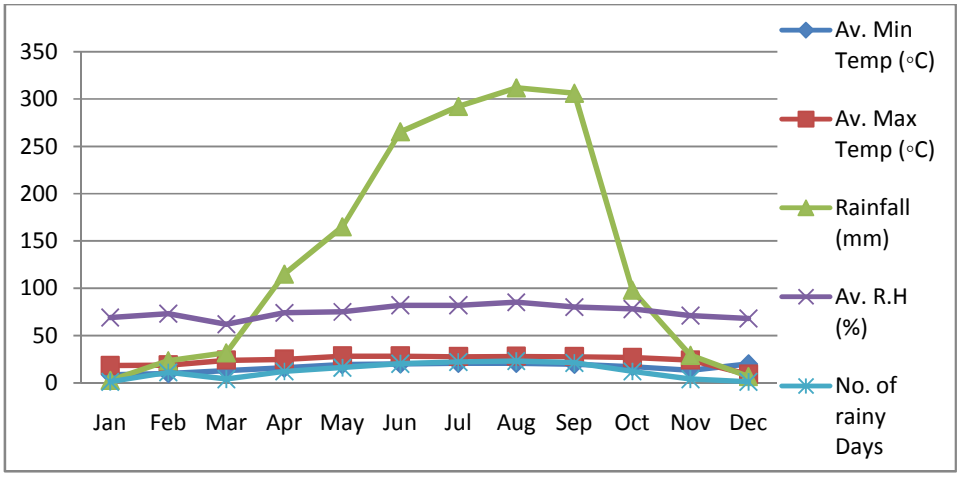


Fig. 1: Graphical representation of meteorological data for 2009.

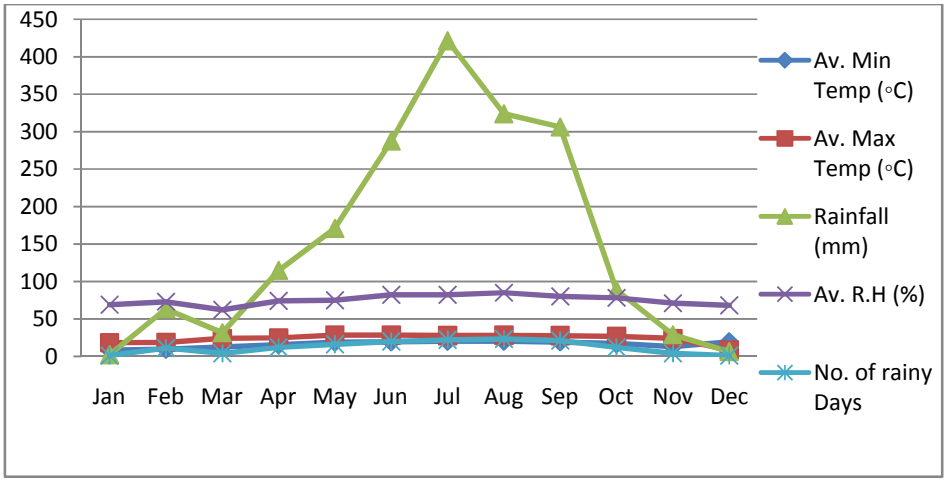


Fig. 2: Graphical representation of meteorological data for 2010.

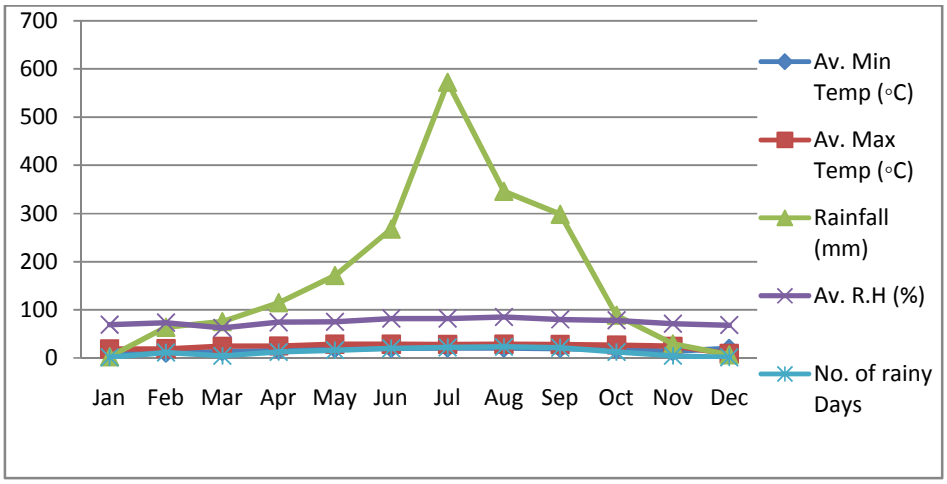


Fig. 3: Graphical representation of meteorological data for 2011.

Sampling

In both the forest and jhumland ecosystems, the sampling collection sites were divided according to the elevation because of the terrain *viz*. upper elevation site, middle elevation site and lower elevation site. In each elevation site, three different plots having a size of 10m x 10m, each at 25-30 m apart, were selected from where soil samples were taken randomly. Sampling of soil microarthropods was initiated in January 2009 and continued till December 2011. Soil samples were taken at one month intervals in the middle week of each month during the study period. All the collections were made in the mornings between 10:00 and 11:00 AM. The soil samples were collected with the help of iron cylindrical core with sampler size of 3.925 cm, which are 10cm in depth and 5cm in diameter.

In order to study the vertical distribution of the soil microarthropods, samples were collected up to a depth of 30 cm and divided into three equal layers namely, 0-10 cm, 10-20 cm and 20-30 cm in both the study sites. All the soil samples were kept in individual polythene bags, labeled and packed to avoid moisture loss and any kind of disturbance to the soil microarthropods during its transit period. In each study site a total of 1944 soil samples were collected during the whole study period. The soil samples were than packed and brought to the laboratory within an average of one hour after the field collection.

Methods of faunal extraction and identification

The extraction of soil microarthropods from the soil was based on the modified Tullgren funnel as described by Crossley and Blair (1991). A 25-Watt electric bulb was used as the source of heat and light. The period of the extraction was 4-5 days at constant temperature of 35 (± 2) ^{o}C depending on the moisture contents of the soil samples. The soil microarthropods were extracted into collecting vials containing 70% alcohol. After the extraction, the vials and the contents were transferred into a petridish and vials were washed several times with 70% alcohol. The extracted soil microarthropods were

preserved in 70% alcohol to which few drops of glycerine were added to prevent desiccation. Identification and counting was done under a binocular microscope.

Physico-chemical factors of soil

The physico-chemical factors of soil such as, temperature, moisture, pH, organic carbon, total nitrogen, available phosphorus, and potassium were analyzed during each sampling period in order to study the impact of these factors in the population changes of soil microarthropods.

Soil temperature: It was recorded from the adjacent area of the sampling plot with the help of soil thermometer for each layer i.e., 0-10 cm, 10-20 cm, and 20-30 cm in both the study sites.

Soil moisture content: The soil moisture contents in both the study sites were determined for each layer *i.e*., 0-10 cm, 10-20 cm, and 20-30 cm by gravimetric method (Misra, 1968 and Wilde *et al.*, 1985).

Soil pH: It was measured at different depths (0-10 cm, 10-20 cm, and 20-30 cm) in both the study sites were determined by using a portable glass electrode pH meter. The soil samples were suspended in double distilled water in the ratio of 1:5 for determination of pH (Jackson, 1958).

Soil organic carbon: The soil organic carbon was determined for total depth (0-30 cm) by oxidation calorimetric method after modified Walkey and Black method (Anderson and Ingram, 1993).

Soil total nitrogen: Soil total nitrogen was determined for total depth (0-30 cm) by acid digestion Kjeldahl procedures (Anderson and Ingram, 1993).

Phosphorus: Soil available phosphorus was determined for total depth (0-30cm) by ammonium molybdate stannous chloride method (Sparling *et al.*, 1985)

Potassium: Soil potassium was determined by flame photometer (Steward, 1971).

Statistical and community analysis

Statistical analysis (standard error, correlation and ANOVA *etc*) were done using software like Microsoft Excel, Origin and Graph Pad-Instat.

In community analysis, species diversity and community similarity were analyzed for Collembola and Acarina using the following formulae:

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

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

Where,

Da = Margalefs Index

S = No. of Species

N = Total No. of Individuals.

(ii) Measure of species diversity based on information theory or related to the concept of uncertainty was calculated after Shannon and Wiener (1949), where,

$$\mathbf{H' = -\sum_{i=1}^{s} Pi \log pi}$$

H' = Measure of Shannon - Wiener Diversity

S = Total No. of Species in a sample

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

(iii) The maximum possible diversity of H' or H max' was calculated using the following formula:

$$H\ max' = \log_2 S$$

Where, *S* = Number of species or category

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

$$J' = H/Hmax'$$

Where,

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

(v) The average faunal resemblance between the forest and jhumland ecosystems was calculated using the following formula.

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

Where,

C = Number of species common to both the communities

S1 = Total number of species in community 1 (forest)

S2 = Total number of species in community 2 (jhumland)

The different physico-chemicals factors *viz.*, soil moisture, pH, soil temperature, total nitrogen, potassium, phosphorus, and organic carbon, were determined in forest and jhumland ecosystem for a period of three years (2009 - 2011). The data for all the parameters studied is given year wise.

Soil Moisture

The total soil moisture content in forest area was higher than in jhumland throughout the study period (Figs. 4-9). Due to vegetation cover, the forest site retains more percentage of soil moisture content in different soil layers when compared to that of jhumland.

Higher rainfall together with high relative humidity followed by vegetation growth leads to the increase in soil moisture content during rainy season. It is interesting to note that the top layer (0-10 cm) in both study sites retained comparatively less percentage of soil moisture than the middle layer (10-20 cm) and basal layer (20-30 cm) throughout the year.

Soil pH

The soil pH in different soil layers is acidic in forest and jhumland (Figs. 10-15). Minimum soil pH was recorded during rainy season followed by winter and summer season. It is interesting to note that there was increase of pH value during rainy season in jhumland than the forest which may be due to low organic matter content and microbial activity which ultimately results in low organic acid production in jhumland ecosystem. The acidic nature of soil pH may be due to the frequent and high rainfall especially in rainy season. Further with the increase of soil moisture content, the soil pH also has the tendency to shift towards acidic nature of the soil *i.e.* decrease in soil pH.

Soil temperature

The soil temperature of both forest and jhumland study sites are represented in Figures 16-21. It has been observed that soil temperature in winter months are recorded to be a bit higher in forest than that of jhumland, while in rainy months jhumland exhibits more soil temperature. The higher soil temperature in jhumland in rainy season may be due to exposure to sun light and low vegetation on the ground than natural forest area which have closed canopy. While temperature decreases in both sites with the increase of

depth, slight increase has been observed in middle layer than top layer during rainy months in forest area. Monthly variation of soil temperature followed the pattern of air temperature which is indicative of the fact that the soil temperature is largely dependent on air temperature.

Soil total nitrogen

Nitrogen in the soil is the most important element for plant development. It is required in large amounts and must be added to the soil to avoid deficiency. Nitrogen is a major part of chlorophyll and the green color of plants. Although nitrogen is the most abundant element in our atmosphere, plants can't use it until it is naturally processed in the soil, or added as fertilizer.

The concentration of soil nitrogen of both forest and jhumland study sites are represented in Figures 22-27. It has been observed that soil nitrogen concentration was higher in forest than in jhumland ecosystem.

Soil Potassium

Potassium is a key plant nutrient, and is the only essential plant nutrient that is not a constituent of any plant part. It aids in tolerance to stresses such as cold/hot temperatures, drought, wear and pest problems, and also catalyses many of the enzymatic processes in the plant. Another key role of potassium is osmoregulation *i.e.*, maintains high daily cell turgor pressure which affects wear tolerance, affects cell elongation for growth and most importantly itregulates the opening and closing of the stomates which affect transpirational cooling and carbon dioxide uptake for photosynthesis.

The soil potassium of both forest and jhumland study sites are represented in Figures 28-33. It has been observed that soil potassium concentration was higher in forest than in jhumland ecosystem.

Soil available Phosphorus

Phosphorus is a component of the complex nucleic acid structure of plants and animals, which regulates protein synthesis. Phosphorus is, therefore, important in cell division and development of new tissue. Phosphorus is also associated with complex energy transformations in the plant. It is an essential element classified as a macronutrient because of the relatively large amounts required by plants. It is one of the three nutrients generally added to soils in fertilizers. One of the main roles of Phosphorus in living organisms is in the transfer of energy. Organic compounds that contain P are used to transfer energy from one reaction to drive another reaction within cells. Adequate Phosphorus availability for plants stimulates early plant growth and hastens maturity.

The soil available phosphorus of both forest and jhum land study sites are represented in Figures 34-39. It has been observed that soil available phosphorus concentration was higher in forest than in jhumland ecosystem.

Soil organic carbon

Soil carbon, or soil organic carbon (SOC) as it is more accurately known, is the carbon stored within soil. It is part of the soil organic matter (SOM), which includes other important elements such as calcium, hydrogen, oxygen, and nitrogen. Soil organic matter is made up of plant and animal materials in various stages of decay. Un-decomposed materials on the surface of the soil, such as leaf litter, are not part of the organic matter until they start to decompose.

The soil organic carbon is comparatively more in forest than the jhumland (Figs. 40-45). It may be due to the higher accumulation of litter and higher decomposition rate of organic matter in the natural forest than the jhumland where the vegetation is very sparse. The maximum soil organic matter was recorded during rainy season followed by summer and winter season in both the study sites. High status of organic carbon in rainy season

may be due to higher decomposition rate of litter and availability of all microclimatic conditions which enhances the decomposition rate.

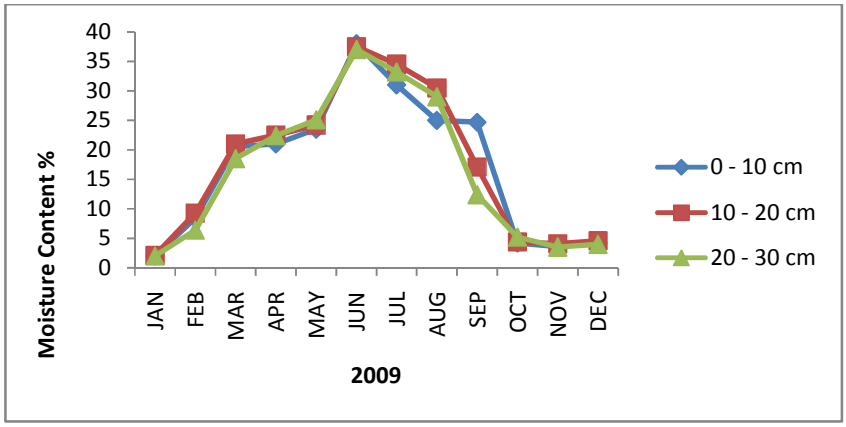


Fig. 4: Soil moisture content in forest for 2009.

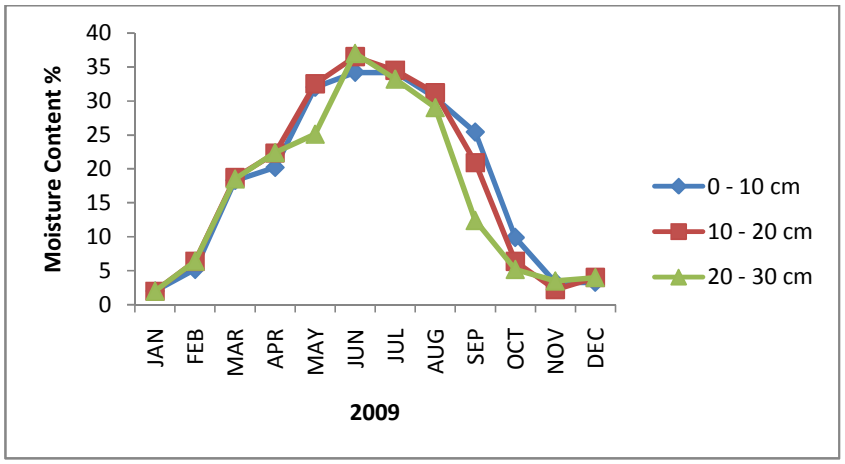


Fig. 5: Soil moisture content in jhumland for 2009.

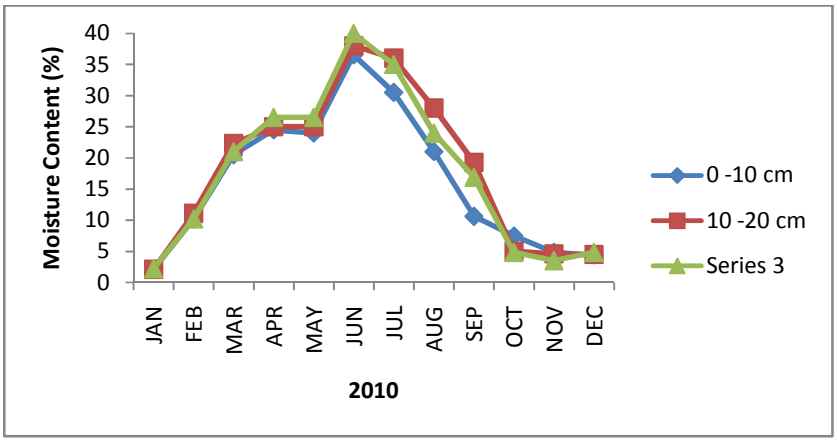


Fig. 6: Soil moisture content in forest for 2010.

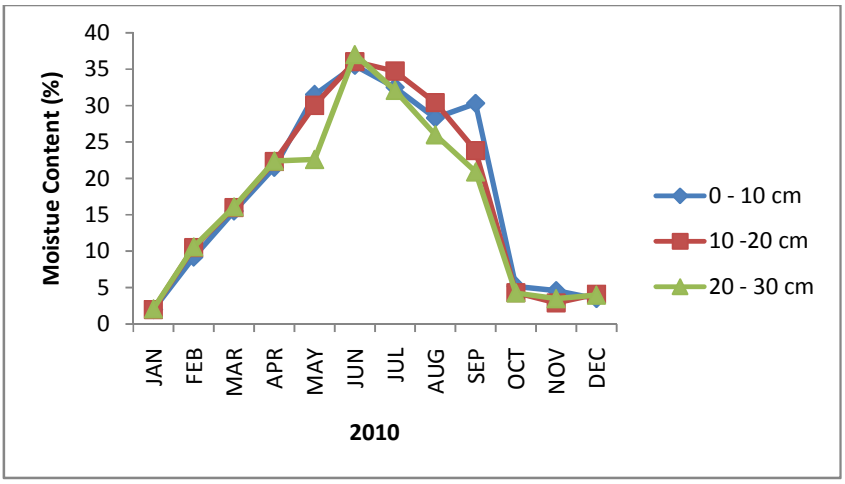


Fig. 7: Soil moisture content in jhumland for 2010.

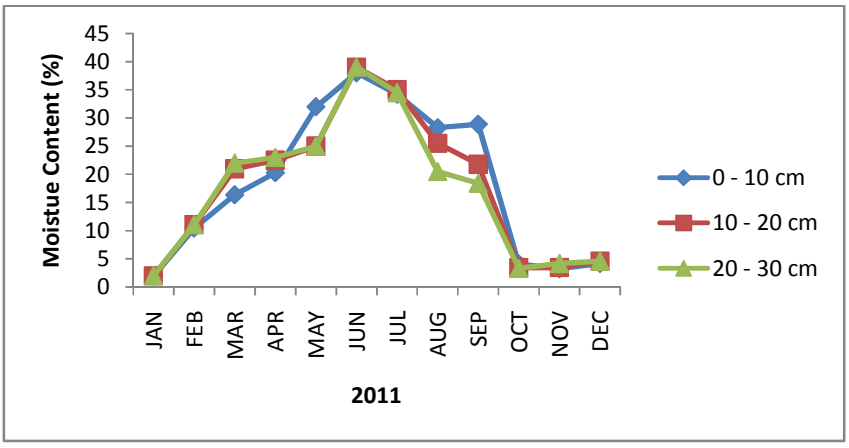


Fig. 8: Soil moisture content in forest for 2011.

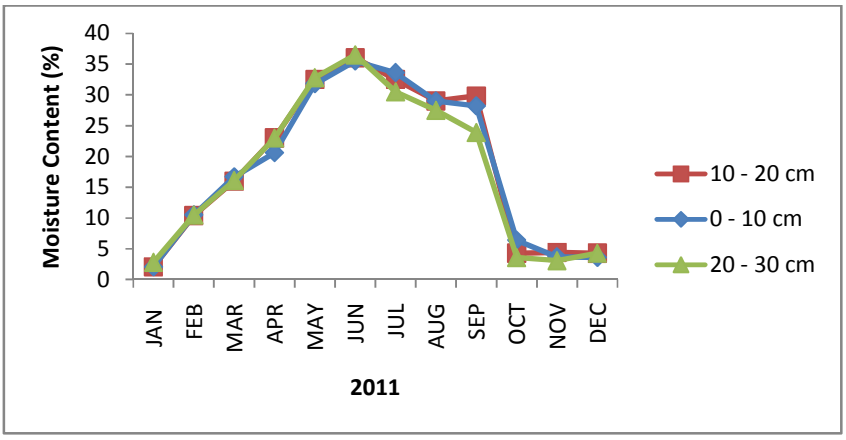


Fig. 9: Soil moisture content in jhumland for 2011.

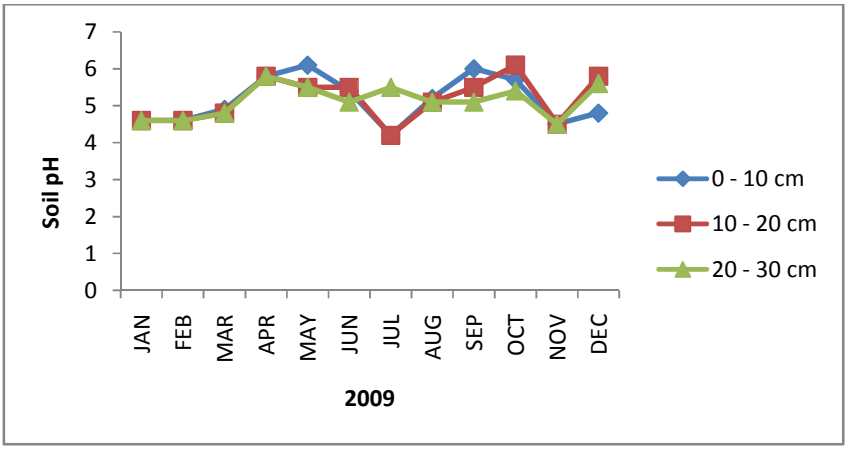


Fig. 10: Soil pH in forest for 2009.

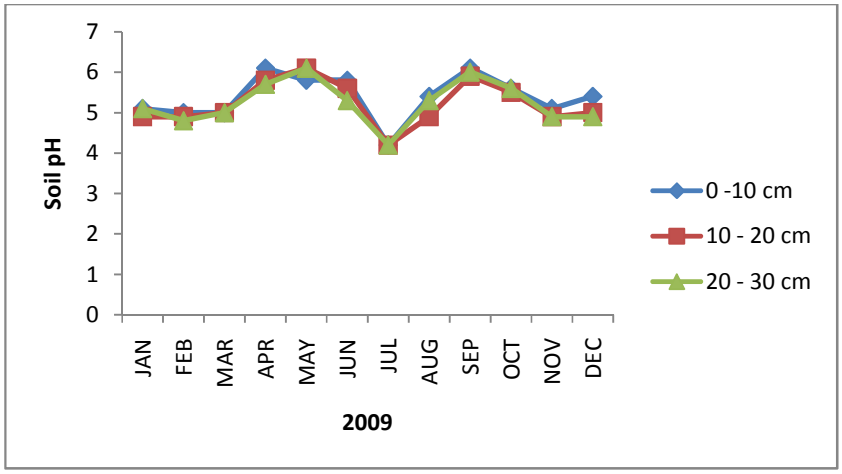


Fig. 11: Soil pH in jhumland for 2009.

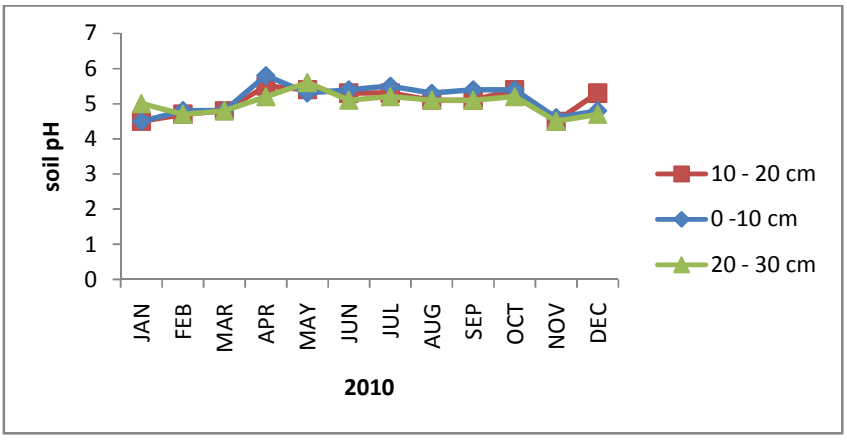


Fig. 12: Soil pH in forest for 2010.

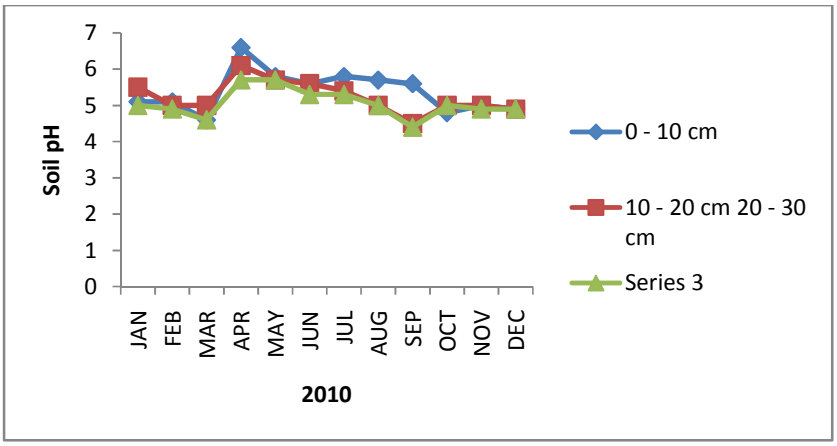


Fig. 13: Soil pH in jhumland for 2010.

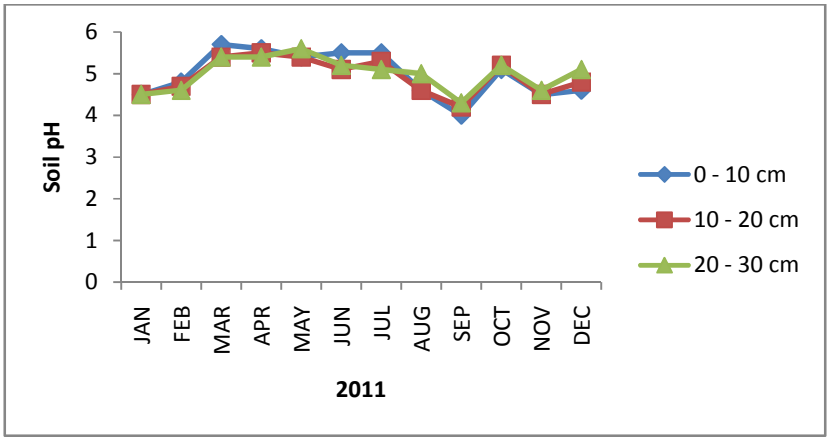


Fig. 14: Soil pH in forest for 2011.

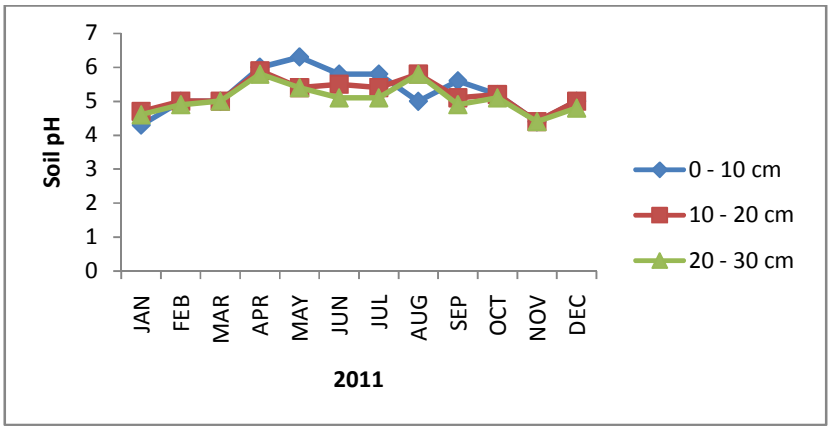


Fig. 15: Soil pH in jhumland for 2011.

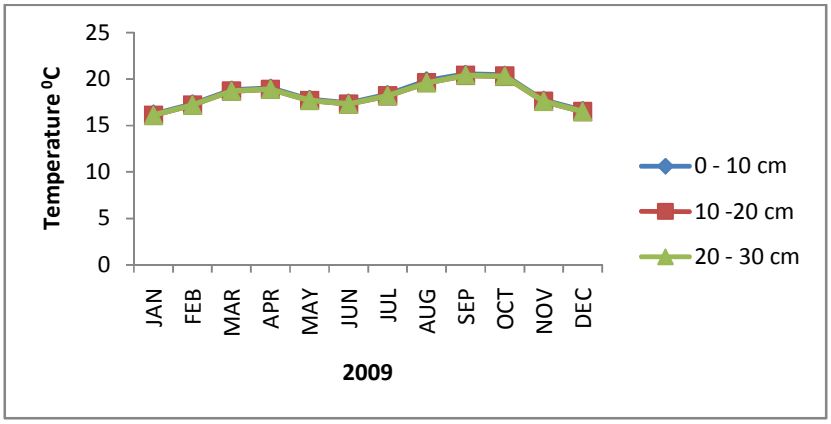


Fig. 16: Soil temperature in forest for 2009.

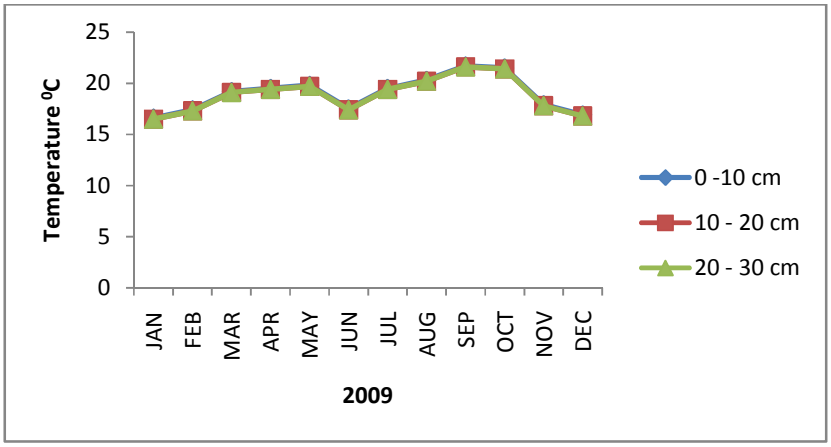


Fig. 17: Soil temperature in jhumland for 2009.

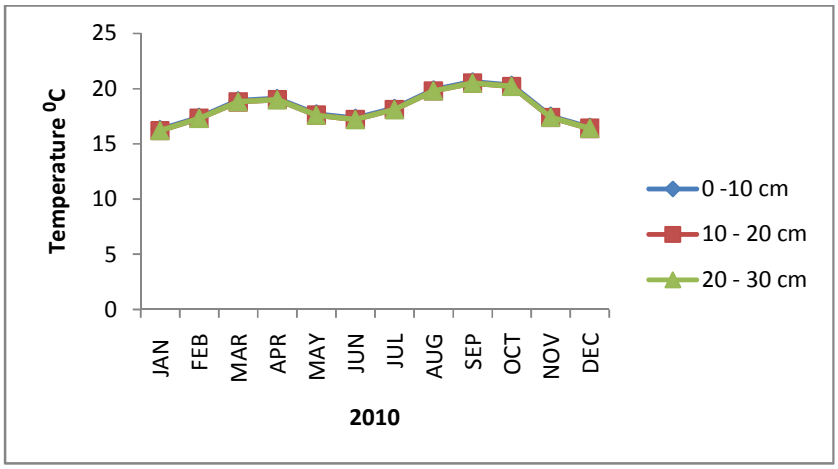


Fig. 18: Soil temperature in forest for 2010.

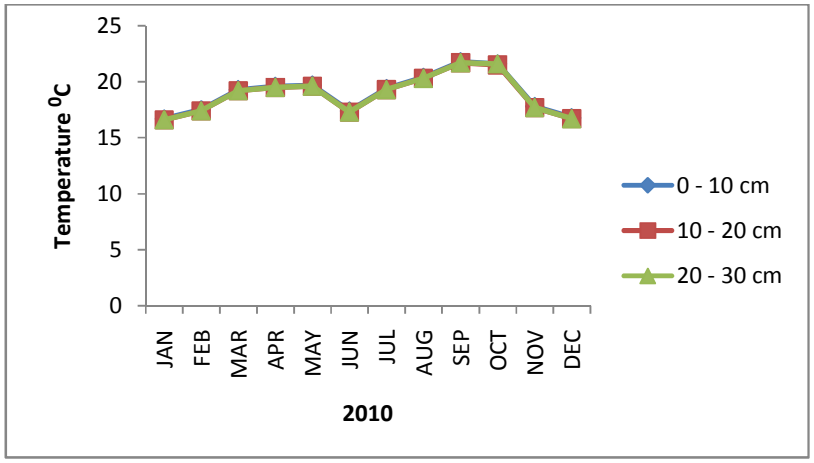


Fig. 19: Soil temperature in jhumland for 2010.

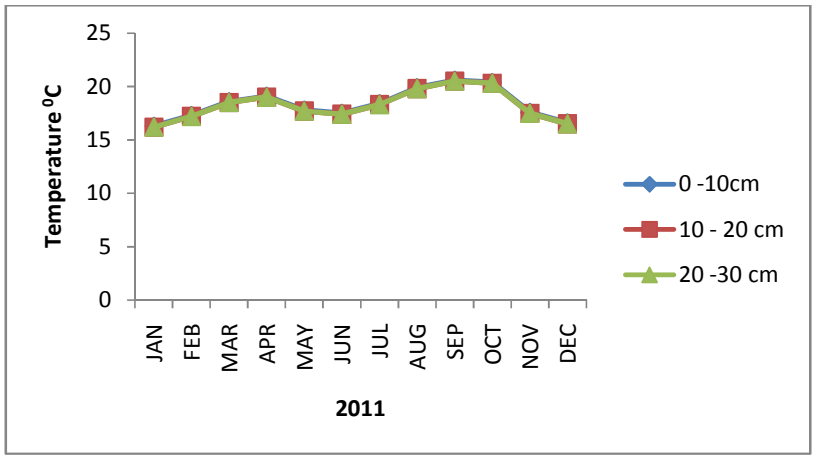


Fig. 20: Soil temperature in forest for 2011.

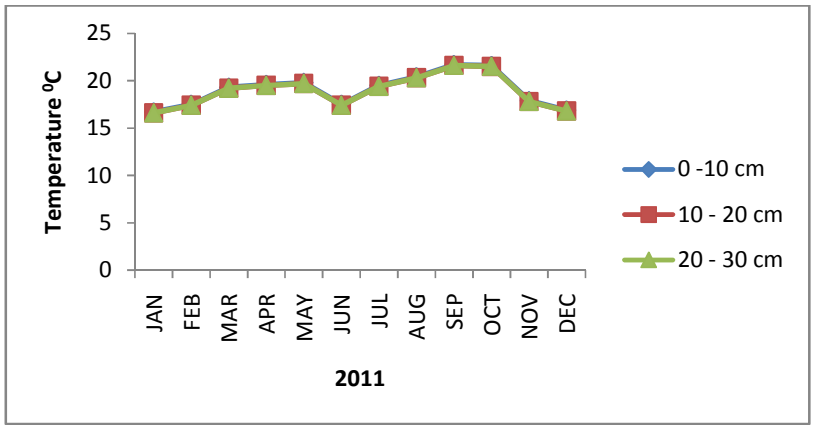


Fig. 21: Soil temperature in jhumland for 2011.

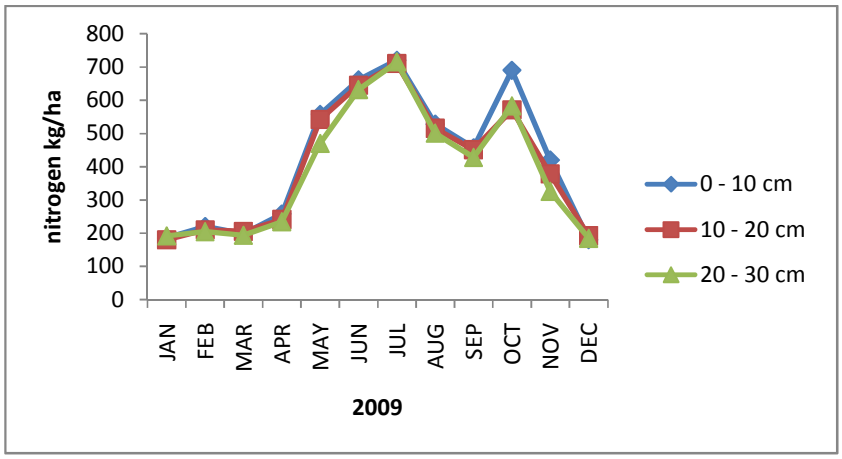


Fig. 22: Soil nitrogen concentration in forest for 2009.

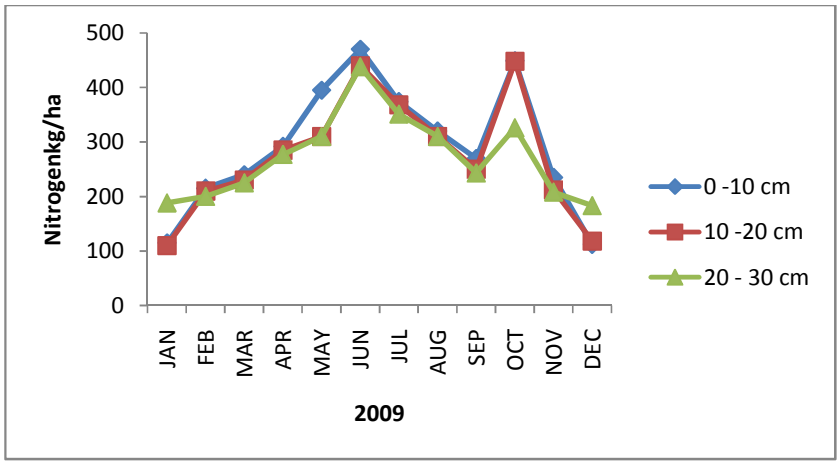


Fig. 23: Soil nitrogen concentration in jhumland for 2009.

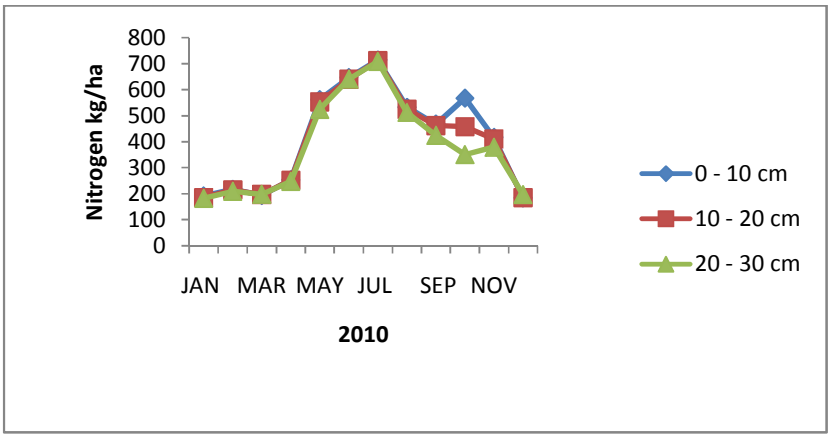


Fig. 24: Soil nitrogen concentration in forest for 2010.

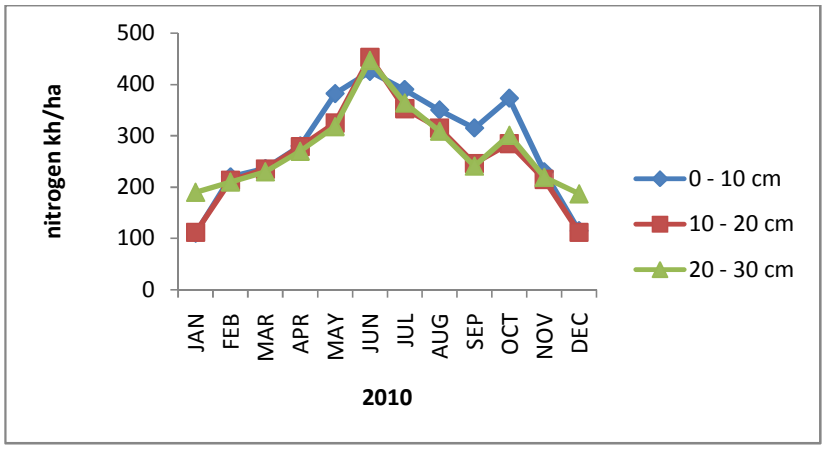


Fig. 25: Soil nitrogen content in jhumland for 2010.

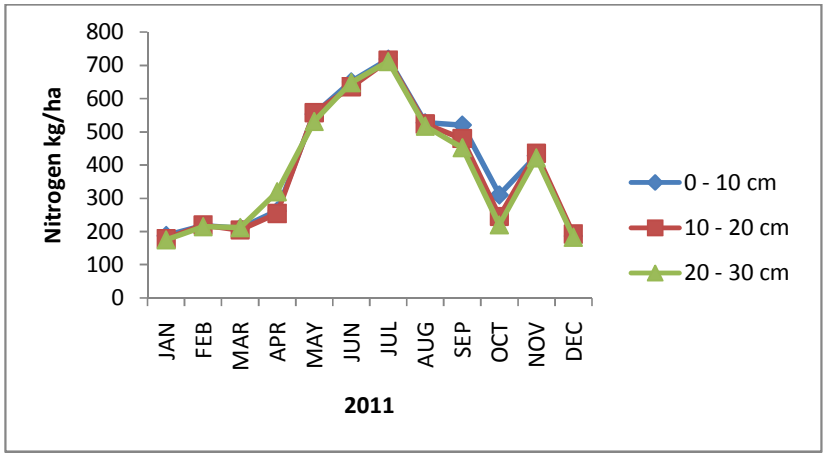


Fig. 26: Soil nitrogen concentration in forest for 2011.

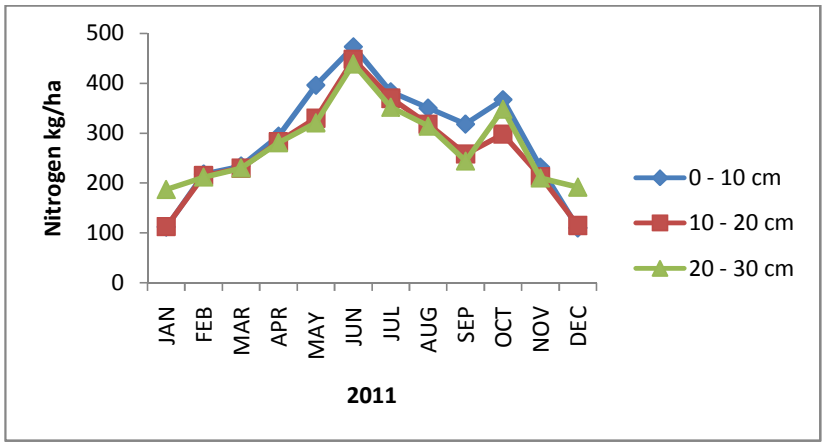


Fig. 27: Soil nitrogen concentration in jhumland for 2011.

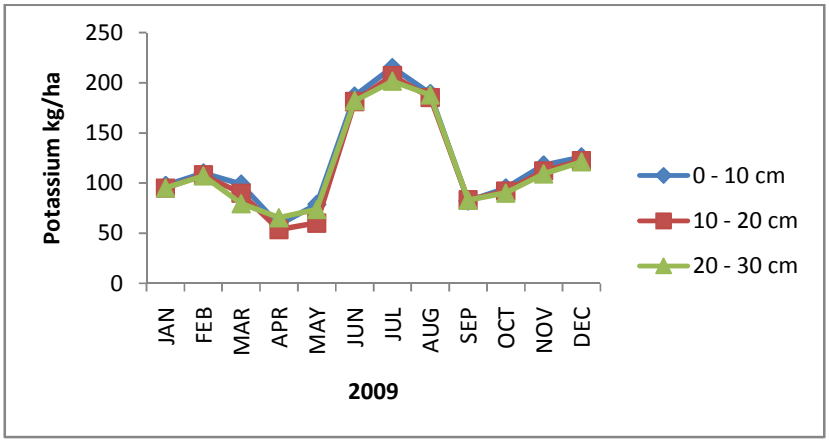


Fig. 28: Soil potassium concentration in forest for 2009.

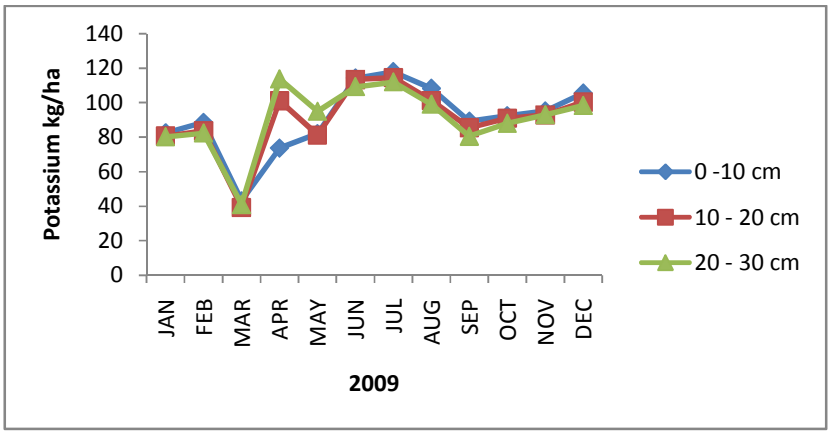


Fig. 29: Soil potassium concentration in jhumland for 2009.

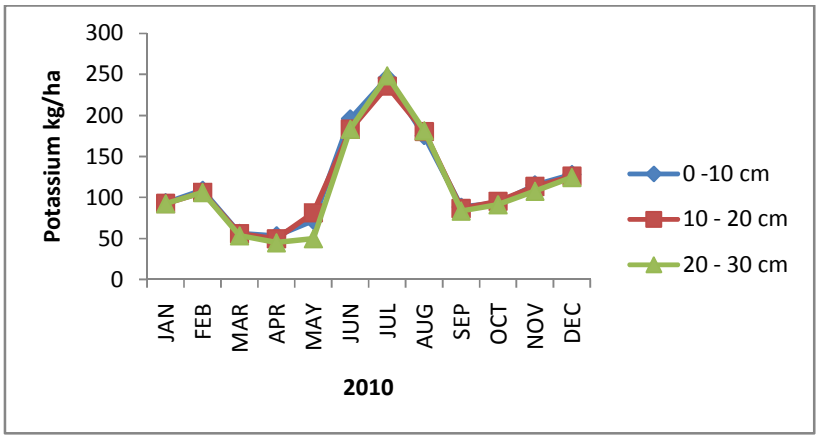


Fig. 30: Soil potassium concentration in forest for 2010.

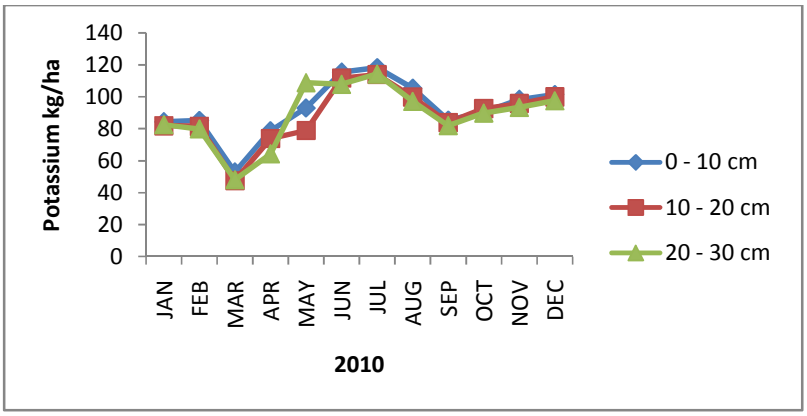


Fig. 31: Soil potassium concentration in jhumland for 2010.

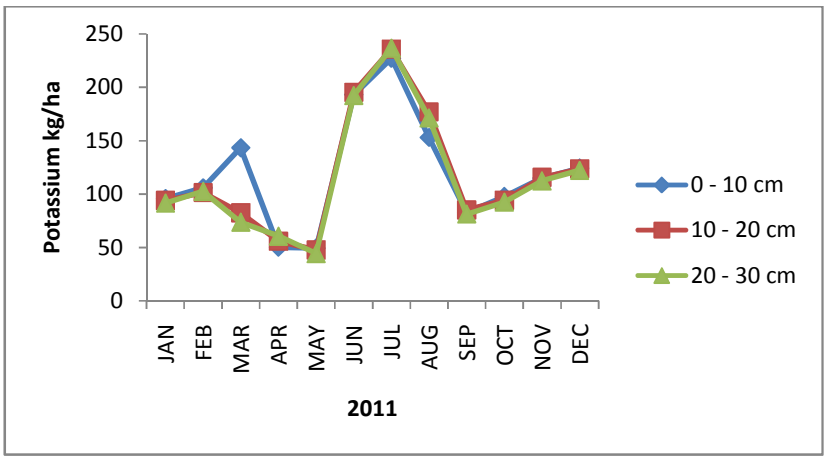


Fig. 32: Soil potassium concentration in forest for 2011.

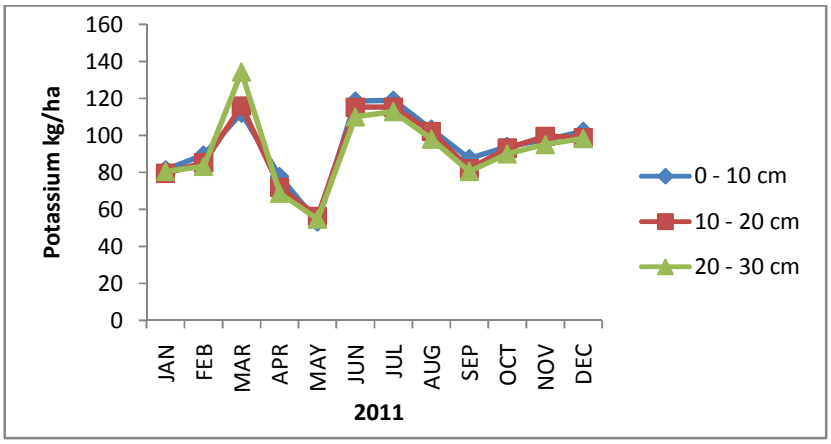


Fig. 33: Soil potassium concentration in jhumland for 2011.

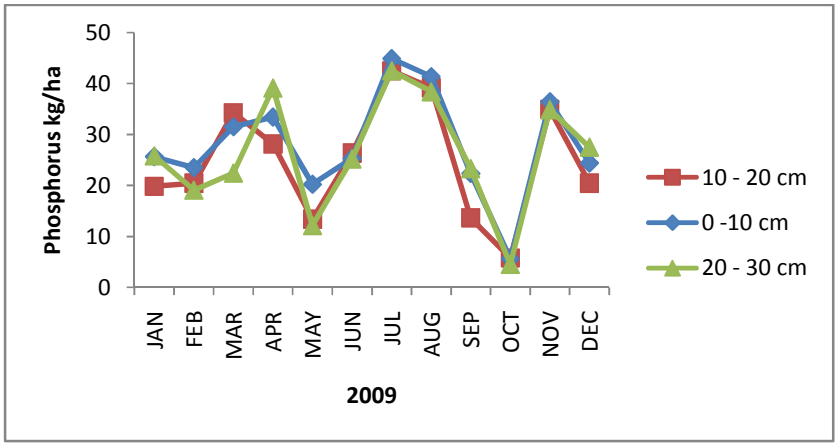


Fig. 34: Soil phosphorus concentration in forest for 2009.

Fig. 35: Soil phosphorus concentration in jhumland for 2009.

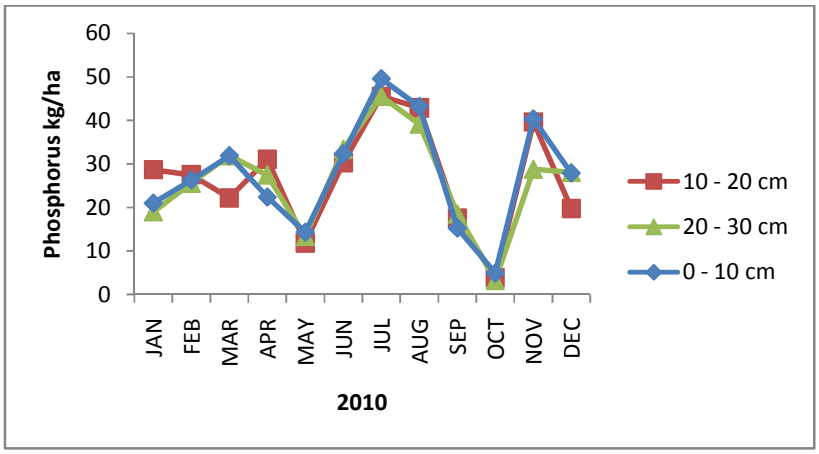


Fig. 36: Soil phosphorus concentration in forest for 2010.

Fig. 37: Soil phosphorus concentration in jhumland for 2010.

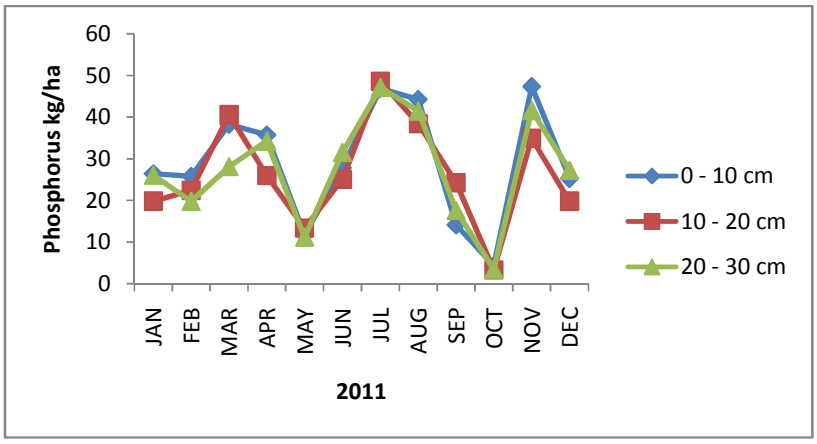


Fig. 38: Soil phosphorus concentration in forest for 2011.

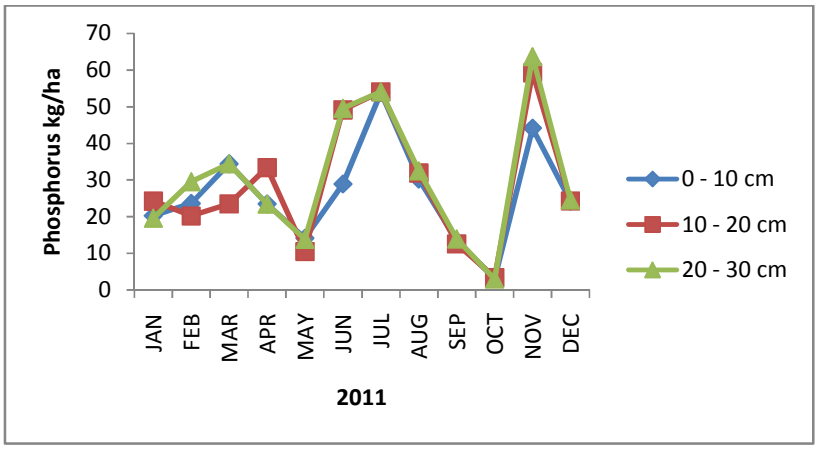


Fig. 39: Soil phosphorus concentration in jhumland for 2011.

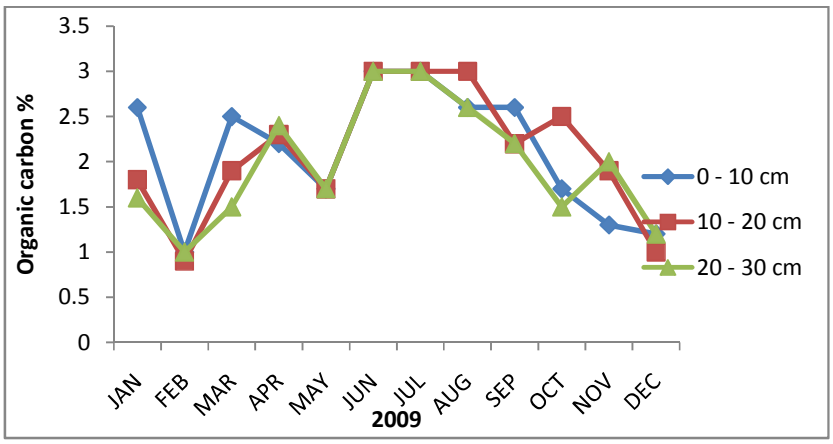


Fig. 40: Soil organic carbon concentration in forest for 2009.

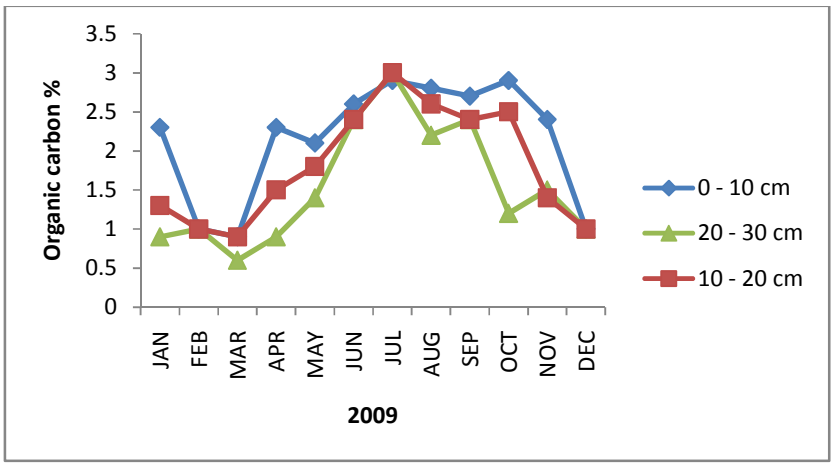


Fig. 41: Soil organic carbon concentration in jhumland for 2009.

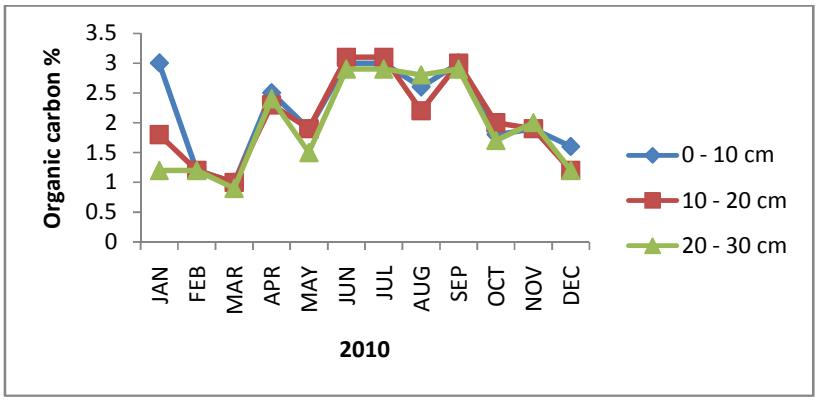


Fig. 42: Soil organic carbon concentration in forest for 2010.

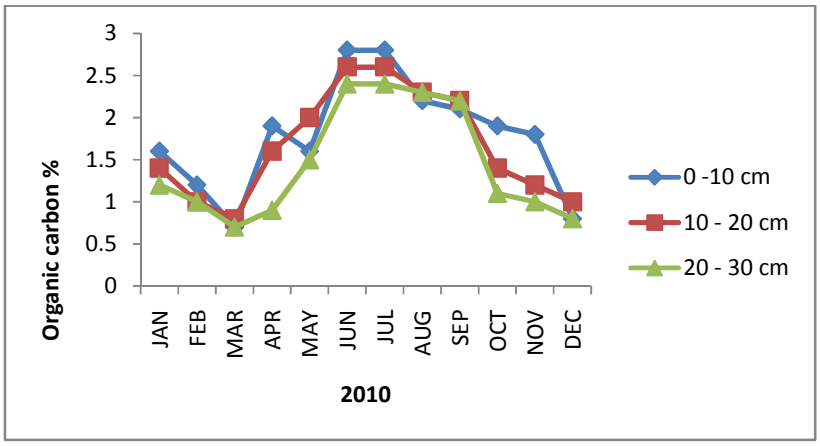


Fig. 43: Soil organic carbon concentration in jhumland for 2010.

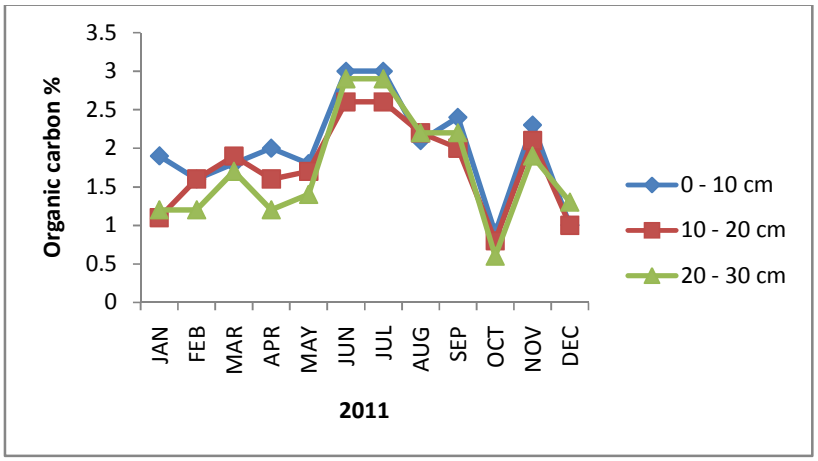


Fig. 44: Soil organic carbon concentration in forest for 2011.

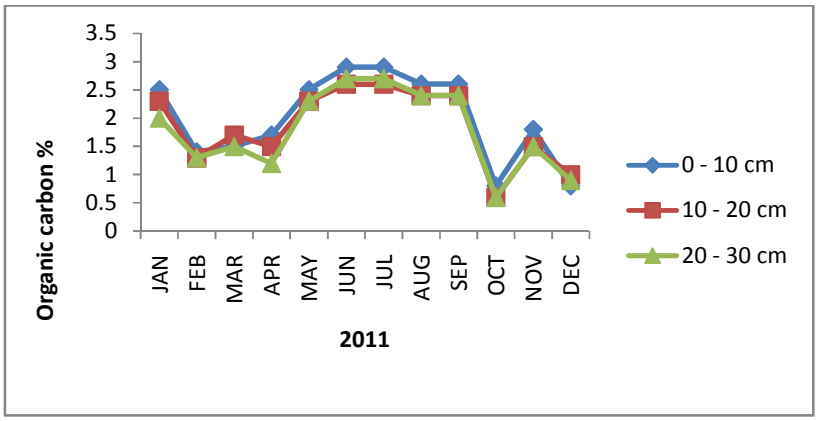


Fig. 45: Soil organic carbon concentration in jhumland for 2011.

Annual population density and vertical distribution of Acarina

During the study of the soil microarthropods, it was observed that the total annual population density of Acarina and their distribution pattern in 3 (three) different depths *i.e.*, 0-10 cm, 10-20 cm, 20-30 cm of the soil layers showed higher population density in forest ecosystem and this may be because of the rich vegetation, physico-chemical factors and absence of human interference. In case of the jhumland ecosystem, the population density of Acarina was lesser as compared to forest ecosystem and this may be due to slash and burn, sparse vegetation and anthropogenic practices.

In forest ecosystem, the total annual population density of Acarina recorded was 428.42 x 10^2 m^{-2} which contributed 43.38 % of the total soil microarthropod population. Population density of Acarina showed decreasing trend with increase in soil depth in different soil layers *i.e.* 205.39 x 10^2 m^{-2} (48.34 %) at 0-10cm, 130.68 x 10^2 m^{-2} (30.76 %) at 10-20 cm and 88.75 x 10^2 m^{-2} (20.89 %) at 20-30 cm. The percentage contribution of Acarina to the total soil microarthropods decreased with depth in the experimented soil layers *i.e.*, 53.43 % at 0-10 cm, 42.84 % at 10-20 cm and 33.89 % at 20-30 cm respectively (Table 4).

In jhumland ecosytem, the total annual population density of Acarina was 264.70 x 10^2 m^{-2} contributing 30.97 % to the total soil microarthropods population. At different soil layers, population density of Acarina showed decreasing trend with increase in soil depth *i.e.* 142.43 x 10^2 m (53.80 %) at 0-10 cm, 92.18 x 10^2 m^{-2} (34.82 %) at 10-20 cm and 30.09 x 10^2 m^{-2} (11.36 %) at 20-30 cm. Acarina constituted 43.44 %, 32.86 % and 16.62 % at 0-10 cm, 10-20 cm and 20-30 cm soil layers respectively to the total soil microarthropods (Table 4).

Table 4: Total numbers and percentage of Acarina

(A= Percentage contribution among the soil layers i.e. 0-10cm, 10-20cm and 20-30cm and represent the number of microarthropods in the layer with respect to total of all the layers in that sampled area).

(B= Percentage contribution to the total soil microarthropods in each layer respectively)

Forest ecosystem

Soil layer (cm)	Numbers ± S.E.	A	*B*
0-10	205.39 ± 0.33	48.34	53.43
10-20	130.68 ± 0.27	30.76	42.84
20-30	88.75 ± 0.69	20.89	33.89
Total	424.82 ± 0.68	100.00	43.38

Jhumland ecosystem

Soil layer (cm)	Numbers ± S.E.	A	*B*
0-10	142.43 ± 0.81	53.80	43.44
10-20	92.18 ± 0.52	34.82	32.86
20-30	30.09 ±0.58	11.36	16.62
Total	264.70 ± 0.98	100.00	30.97

Seasonal variation of Acarina

Table 5: Seasonal variation of Acarina *(Numbers ± S.E) x $10^2 m^{-2}$*

Forest ecosystem

Season	Soil layers			Total
	0-10 cm	10-20 cm	20-30 cm	
Winter	42.61 ±0.90	20.43±0.26	14.21 ±0.71	77.25 ± 0.53
Summer	65.02 ± 0.52	27.54± 0.83	23.64 ± 0.43	116.20 ± 0.42
Rainy	97.76 ± 0.28	82.71 ± 0.21	50.90 ± 0.85	231.37± 0.14
Annual	205.39 ± 0.33	130.68± 0.27	88.75 ± 0.69	424.82 ± 0.68

Jhumland ecosystem

Season	Soil layers			Total
	0-10 cm	10-20 cm	20-30 cm	
Winter	33.45 ± 0.30	21.21 ± 0.12	6.73 ± 0.17	61.39 ± 0.48
Summer	42.91 ± 0.15	29.26 ± 0.11	8.56 ± 0.83	80.73 ± 0.97
Rainy	66.07 ± 0.49	41.71 ± 0.24	14.80 ± 0.21	122.58 ± 0.33
Annual	142.43 ± 0.81	92.18 ± 0.52	30.09 ± 0.58	264.70 ± 0.98

In the forest ecosystem, population density of Acarina was higher during the rainy season (231.37 x 10^2 m^{-2}) followed by summer season (116.20 x 10^2 m^{-2}) and winter season (77.25 x 10^2 m^{-2}) respectively. The seasonal vertical distribution pattern of Acarina showed a decreasing trend with increase in soil depth. The highest vertical population density was recorded in 0-10 cm during rainy season with its value of 97.76 x 10^2 m^{-2} and the lowest was recorded in 20-30 cm during winter season with value of 14.21 x 10^2 m^{-2} (Table 4).

In the jhumland ecosystem, population density of Acarina was higher during the rainy season (122.58 x 10^2 m^{-2}) followed by summer season (80.73 x10^2 m^{-2}) and winter season (61.39 x10^2m"^{2}) respectively. The pattern of seasonal vertical distribution in Acarina showed a decreasing trend with increase in soil depth in all the seasons. The maximum vertical population density was recorded in 0-10 cm during rainy season with a value of 66.07 x10^2 m^{-2} and the minimum was recorded in 20-30 cm during winter season with value of 6.73 x10^2 m^{-2} (Table 5).

Monthly variation of Acarina

In the study conducted, the monthly variation of total population density of Acarina in forest ecosystem and jhumland ecosystem was found to be the highest in the month of August (68.21 x 10^2 m^{-2}) and (53.18 x 10^2 m^{-2}) respectively.

In the forest ecosystem, Acarina population showed maximum density in the month of August (69.41 x 10^2 m^{-2}) and minimum in the month of January (12.06 x 10^2 m^{-2}) at 0-10 cm soil depth. At the depth 10-20 cm, maximum was recorded in the month of August (32.42 x 10^2 m^{-2}) and the minimum in the month of January (6.22 x 10^2 m^{-2}). Accordingly at 20-30 cm depth, the maximum was recorded in the month of August (22.06 x 10^2 m^{-2}) and minimum in the month of January (2.66 x 10^2 m^{-2}) (Fig. 46).

In jhumland ecosytem, Acarina population at 0-10 cm soil depth showed maximum in the month of August (38.42 x 10^2 m^{-2}) and minimum in the month of January (6.51 x 10^2 m^{-2}). At 10-20 cm soil depth, maximum was recorded in the month of August (14.31 x 10^2 m^{-2}) and minimum in the month of January (3.09 x 10^2 m^{-2}). While at 20-30 cm soil depth, maximum was recorded in the month of August (14.35 x 10^2 m^{-2}) and minimum in the month of January (1.39 x 10^2 m^{-2}) (Fig. 46).

Annual population density and vertical distribution of Collembola

The total annual population density of Collembola and their distribution pattern in 3 (three) different depths *i.e.*, 0-10 cm, 10-20 cm, 20-30 cm of the soil layers showed the forest ecosystem has higher population density to that of the jhumland ecosystem. In case of Collembola, the higher concentration of population was found in the top layer of the soil.

In forest ecosystem, the total annual population density of Collembola recorded was 324.69 x10^2 m^{-2} which contributed to 26.27 % of the total soil microarthropods population. Population density of Collembola showed decreasing pattern with increase in soil depth in different soil layers *i.e.*, 152.01 x 10^2 m^{-2} (46.81%) at 0-10 cm, 102.17x 10^2 m^{-2} (31.46 %) at 10-20 cm and 70.51 x 10^2 (21.17%) respectively.

In jhumland ecosystem, the total annual population density of Collembola recorded was 222.42 x 10^2 m^{-2} contributing 34.37 % to the total soil microarthropods population.The population density of Collembola showed decreasing pattern with increase in soil depth *i.e.*, 123.09 x 10^2 m^{-2} (55.38 %) at 0-10cm, 70.72 x 10^2 m^{-2} (31.82%) at 10-20 cm and 28.61 x 10^2 m^{-2} (12.80 %) at 20-30 cm. Collembola constitute 46.88 %, 37.34 % and 18.89 % at 0-10 cm, 10-20 cm and 20-30 cm soil layers respectively to the total soil microarthropods.

Table 6: Total numbers and percentage of Collembola

(A= Percentage contribution among the soil layers i.e. 0-10, 10-20 and 20-30cm)
(B= Percentage contribution to the total soil microarthropods in each layer respectively)
(Numbers ± S.E) x $10^2 m^{-2}$

Forest ecosystem

Soil layer (cm)	**Numbers ± S.E.**	**A**	***B***
0-10	152.01 ± 0.72	46.81	38.80
10-20	102.17 ± 0.50	31.46	27.10
20-30	70.51 ± 0.47	21.17	12.93
Total	324.69 ± 0.96	100.00	26.27

Jhumland ecosystem

Soil layer (cm)	**Numbers ± S.E.**	**A**	***B***
0-10	123.09 ± 0.41	55.38	46.88
10-20	70.72 ± 0.75	31.82	37.34
20-30	28.61 ± 0.48	12.80	18.89
Total	222.24 ± 0.75	100.00	34.37

Seasonal variation of Collembola

Table 7: Seasonal variation of Collembola ***(Numbers ± S.E) x $10^2 m^{-2}$***

Forest ecosystem.

Season	Soil layers			Total
	0-10 cm	10-20 cm	20-30 cm	
Winter	34.81 ± 0.56	20.52 ± 0.51	18.01 ±0.61	73.34 ± 0.61
Summer	52.14. ± 0.83	35.84 ± 0.60	20.08 ± 0.42	108.06 ± 0.76
Rainy	65.06 ± 0.03	45.81 ± 0.05	32.42 ± 0.22	143.29 ± 0.41
Annual	152.01 ± 0.72	102.17± 0.50	70.51± 0.47	324.69 ± 0.96

(B) Jhumland ecosystem.

Season	Soil layers			Total
	0-10 cm	10-20 cm	20-30 cm	
Winter	29.72 ± 0.74	13.94 ± 0.92	7.57 ± 0.11	51.23 ± 0.52
Summer	34.09 ± 0.45	24.02 ± 0.15	8.21 ± 0.13	66.32 ± 0.78
Rainy	59.28 ± 0.67	32.76 ± 0.54	12.83 ± 0.19	104.87 ± 0.38
Annual	123.09 ± 0.41	70.72 ± 0.35	28.61 ± 0.48	222.42 ± 0.75

In the forest ecosystem, population density of collembola was abundant during the rainy season (143.29 $x10^2$ m^{-2}) followed by summer season (108.06 x 10^2 m^{-2}) and winter season (73.34 $x10^2$ m^{-2}) respectively. The seasonal vertical distribution pattern of Collembola showed a decreasing trend with increase in soil depth. The highest vertical population density was recorded in 0-10 cm during rainy season with its value of (65.06 x 10^2 m^{-2}) and the lowest was recorded during winter at 20-30 cm with a value (18.01 x 10^2 m^{-2}).

In the jhumland ecosystem, population density of collembola was higher during the rainy season (104.87 $x10^2$ m^{-2}) followed by summer season (66.32 $x10^2$ m^{-2}) and winter season (51.23 $x10^2$ m^{-2}) respectively. The seasonal vertical distribution pattern of collembolan showed a decreasing trend with increase in soil depth in all the seasons. The maximum vertical population density was recorded in 0-10 cm of rainy season with its value of 59.28 $x10^2$ m^{-2} and the minimum was recorded in 20-30 cm of winter season with value of 7.57 x 102 m^{-2}.

Monthly variation of Collembola

In the study conducted, the monthly variation of total population density of Collembola in forest ecosystem and jhumland ecosystem was found to be the highest in the month of a August (42.22 x 10^2 m^{-2}) and (28.86 x 10^2 m^{-2}) respectively (Fig. 49).

In the forest ecosystem, Collembola population showed maximum in the month of August (42.22 x 10^2 m^{-2}) and minimum in the month of January (7.92 x 10^2 m^{-2}) at 0-10 cm soil depth. At the depth 10-20 cm, maximum was recorded in the month of August (24.80 x 10^2 m^{-2}) and the minimum in the month of January (4.53 x 10^2 m^{-2}). Accordingly at 20-30 cm depth, the maximum was recorded in the month of August (17.01 x 10^2 m^{-2}) and minimum in the month of January (2.26 x 10^2 m^{-2}) (Fig. 50).

In jhumland ecosytem, Collembola population at 0-10 cm soil depth showed maximum in the month of August (28.86 x 10^2 m^{-2}) and minimum in the month of January (2.39 x 10^2 m^{-2}). At 10-20 cm soil depth, maximum was recorded in the month of August (16.18 x 10^2 m^{-2}) and minimum in the month of January (3.10 x 10^2 m^{-2}). While at 20-30 cm soil depth, maximum was recorded in the month of August (10.83 x 10^2 m^{-2}) and minimum in the month of January (1.19 x 10^2 m^{-2}) (Fig. 51).

Annual population density and vertical distribution of other microarthropods

During the study of the soil microarthropods, it was observed that the total annual population density of microarthropods other than Acarina and Collembola, their distribution pattern in 3 (three) different depths *i.e*., 0-10 cm, 10-20 cm, 20-30 cm of the soil layers showed higher population density in forest ecosystem as compared to jhumland ecosystem.

In forest ecosystem, the total annual population density of microarthropods recorded was 267.87x 10^2 m^{-2} which contribute 25.75 % of the total soil microarthropods population. Population density of soil microarthropods showed decreasing trend with increase in soil depth in different soil layers *i.e*., 113.98 x 10^2 m^{-2} (42.55 %) at 0-10 cm, 90.37 x 10^2 m^{-2} (33.73 %) at 10-20 cm and 63.52 x 10^2 m^{-2} (23.71 %) at 20-30 cm. The percentage contribution of other microarthropods except Acarina and collembolla to the total soil microarthropods decreased with the depth in the experimented soil layers *i.e.*, 37.70 % at 0-10 cm, 24.26 % at 10-20 cm and 15.30 % at 20-30 cm respectively.

In jhumland ecosytem, the total annual population density of Acarina was 206.10 x 10^2 m^{-2} contributing 32.50 % to the total soil microarthropods population. At different soil layers, the population density of other soil microarthropods showed decreasing trend with increase in soil depth *i.e.*, 105.54 x 10^2 m^{-2} (51.20 %) at 0-10 cm, 58.03 x 10^2 m^{-2} (28.15%) at 10-20 cm and 42.53 x 10^2 m^{-2} (20.63 %) at 20-30 cm. The other microarthropods

constituted 54.34 %, 31.53 % and 11.64 % at 0-10 cm, 10-20 cm and 20-30 cm soil layers respectively to the total soil microarthropods.

Table 8: Total numbers and percentage of other microarthropods

Forest ecosystem

Soil layer (cm)	Numbers ± S.E.	A	*B*
0-10	113.98 ± 0.95	42.55	37.70
10-20	90.37 ± 0.69	33.73	24.26
20-30	63.52 ± 0.84	23.71	15.30
Total	267.87 ± 0.57	100.00	25.75

Jhumland ecosystem

Soil layer (cm)	Numbers ± S.E.	A	*B*
0-10	105.54 ± 0.46	51.20	54.34
10-20	58.03 ± 0.82	28.15	31.53
20-30	42.53 ± 0.56	20.63	11.64
Total	206.10 ± 0.60	100.00	32.50

Table 9: Seasonal variation of other microarthropods

Forest ecosystem.

Season	Soil layers			Total
	0-10 cm	10-20 cm	20-30 cm	
Winter	21.52 ±0.94	16.34 ± 0.17	10.08 ± 0.91	47.94 ± 0.52
Summer	39.41. ± 0.20	33.02 ± 0.91	25.90 ± 0.70	98.33 ± 0.58
Rainy	53.05 ± 0.33	41.01 ± 0.27	27.54 ± 0.11	121.82 ± 0.54
Annual	113.98± 0.95	90.37 ± 0.69	63.52 ±0.84	267.87±0.57

Jhumland ecosystem.

Season	Soil layers			Total
	0-10 cm	10-20 cm	20-30 cm	
Winter	23.71 ±0.32	10.07 ± 0.63	8.55 ± 0.54	42.33± 0.49
Summer	31.50 ± 0.45	20.42 ± 0.82	14.96 ± 0.41	66.88 ± 0.25
Rainy	50.33 ± 0.61	27.54 ± 0.00	19.02 ± 0.05	96.89 ± 0.27
Annual	105.54± 0.46	58.03 ± 0.82	42.53±0.56	206.10± 0.60

In the forest ecosystem, population density of soil microarthropods was higher during the rainy season (121.82 x 10^2 m^{-2}) followed by summer season (98.33 x 10^2 m^{-2}) and winter season (47.94 x 10^2 m^{-2}) respectively. The seasonal vertical distribution pattern of other microarthropods showed a decreasing trend with increase in soil depth. The highest vertical population density was recorded in 0-10 cm during rainy season with its value of 53.05 x 10^2 m^{-2} and the lowest was recorded in 20-30 cm during winter season (10.08 x 10^2 m^{-2}).

In the jhumland ecosystem, population density of other soil microarthropods was higher during the rainy season (96.89 x 10^2 m^{-2}) followed by summer season (66.88 x10^2 m^{-2}) and winter season (42.33 x 10^2 m^{-2}) respectively. The pattern of seasonal vertical distribution showed a decreasing trend with increase in soil depth in all the seasons. The maximum vertical population density was recorded in 0-10 cm of rainy season with its value of 50.33 x10^2 m^{-2} and the minimum was recorded in 20-30 cm of winter season with value of 8.55 x10^2 m^{-2}.

The population of other soil microarthropods was higher during rainy season followed by summer season and winter season in both the two ecosystems. The reason may be due to high content of physico-chemical factors and decomposition of nutrients during those seasons.

Monthly variation of others soil microarthropods

In the study conducted, the monthly variation of total population density of other soil microarthropods in forest ecosystem was found to be the highest in the month of August (14.87 x 10^2 m^{-2}) and in jhumland ecosystem maximum was found in August and September (11.91 x 10^2 m^{-2}) respectively

In the forest ecosystem, the population density showed maximum in the month of August (14.87 x 10^2 m^{-2}) and minimum in the month of January (2.91 x 10^2 m^{-2}) at 0-10 cm soil depth. At the depth 10-20 cm, maximum was recorded in the month of August (4.98 x 10^2 m^{-2}) and the minimum in the

month of February (1.97 x 10^2 m^{-2}). Accordingly at 20-30cm depth, the maximum was recorded in the month of August (4.01 x 10^2 m^{-2}) and minimum in the month of January (1.66 x 10^2 m^{-2}).

In jhumland ecosystem, population density at 0-10 cm soil depth showed maximum in the month of August (6.89 x 10^2 m^{-2}) and minimum in the month of January (1.99 x 10^2 m^{-2}) . At 10-20 cm soil depth, maximum was recorded in the month of August (4.36 x 10^2 m^{-2}) and minimum in the month of January (0.98 x 10^2 m^{-2}). While at 20-30 cm soil depth, maximum was recorded in the month of October (2.87 x 10^2 m^{-2}) and minimum in the month of January (0.64 x 10^2 m^{-2}).

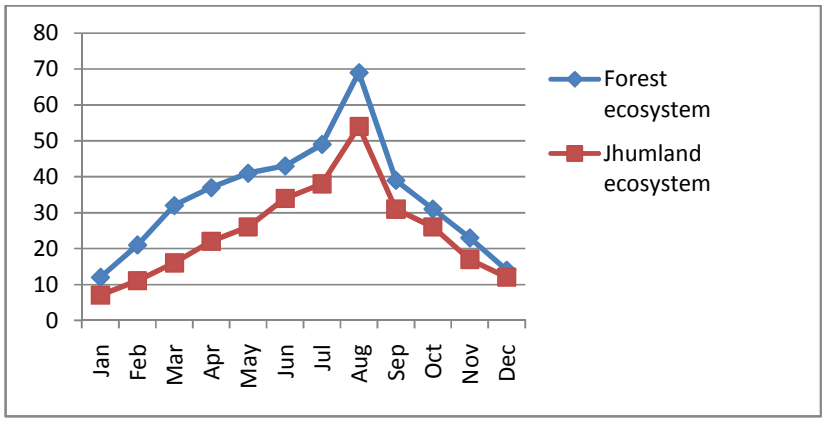


Fig. 46: Monthly variation of total Acarina population density in forest and jhumland ecosystem (Numbers x $10^2 m^{-2}$).

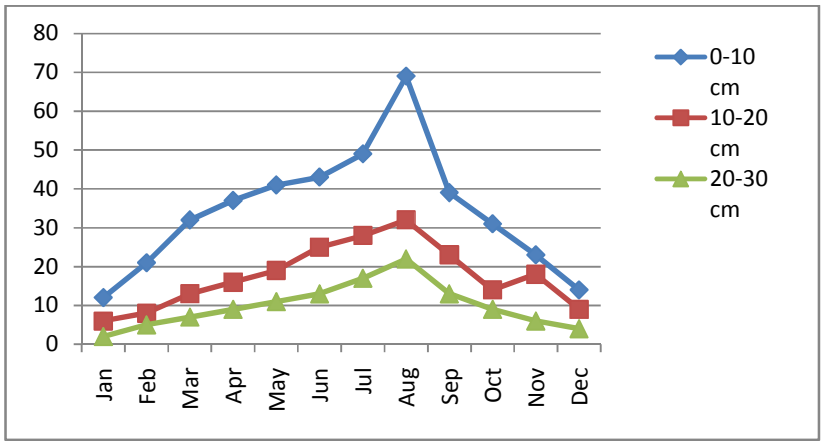


Fig. 47: Monthly variation of total Acarina population density in different soil layers of forest ecosystem (Numbers x $10^2 m^{-2}$).

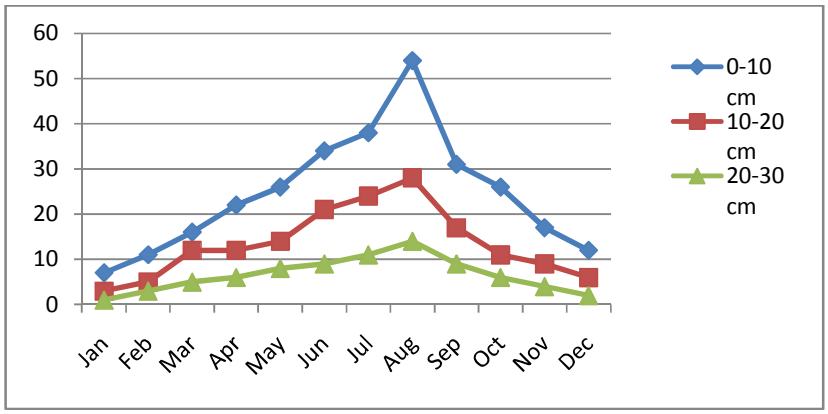


Fig. 48: Monthly variation of total Acarina population density in different soil layers of jhumland ecosystem (Numbers x 10^2m^{-2}).

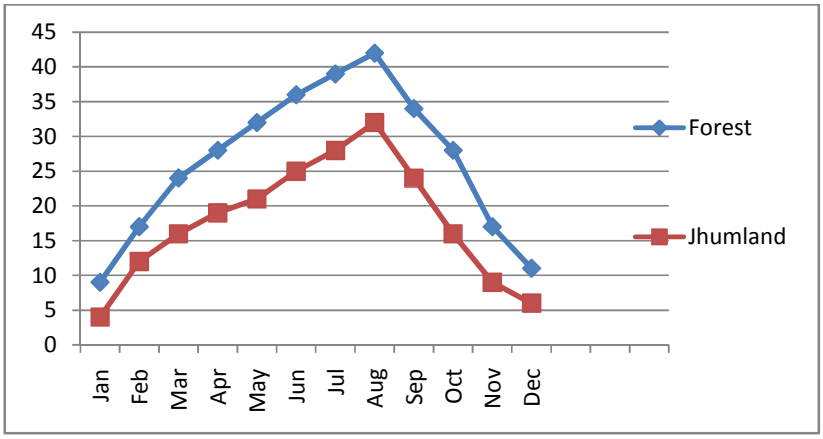


Fig. 49: Monthly variation of total collembola population density in forest and jhumland ecosystem (Numbers x 10^2m^{-2}).

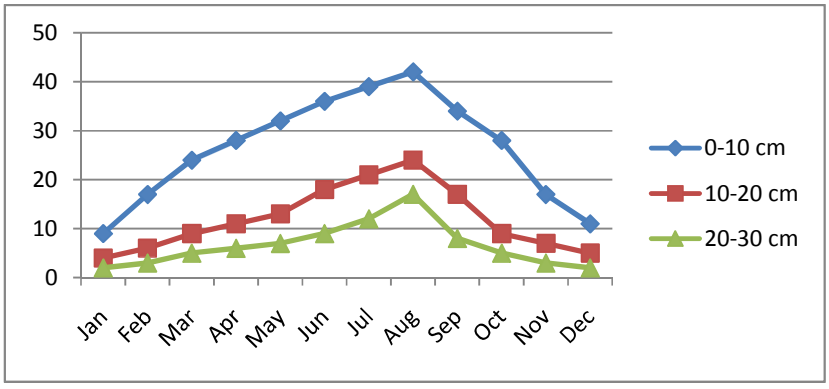


Fig. 50: Monthly variation of total Collembola population density in different soil layers of forest ecosystem (Numbers x 10^2m^{-2}).

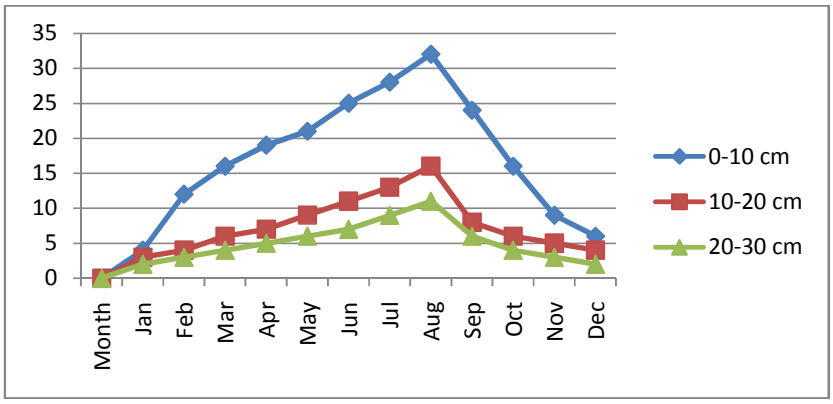


Fig. 51: Monthly variation of total Collembola population density in different soil layers of jhumland ecosystem (Numbers x $10^2 m^{-2}$).

Effect of soil moisture

In forest ecosystem, it was observed that the soil moisture content at 0-10 cm showed positive and significant relationship with Acarina ($r = 0.7622$, $p < 0.05$), Collembolla ($r = 0.7793$, $p < 0.05$) and other soil microarthropods ($r = 0.7253$, $p < 0.05$). At 10-20cm soil layer, it showed positive significant relationship with Acarina ($r = 0.8099$, $p < 0.05$), but showed negative with Collembolla ($r = - 0.0.2861$, $p < 0.05$) and slight significant relationship with other soil microartropods ($r = 0.5972$, $p < 0.05$). At the soil layer 20-30cm, it showed positive significant relationship with Acarina ($r = 0.7276$, $p < 0.05$), but negative relationship with Collembolla ($r = - 0.2501$, $p < 0.05$), other soil microarthropods ($r = - 0.1233$, $p < 0.05$) and the total microarthropods. It was observed that there was positive and significant correlationship between soil moisture and Acarina but insignificant relationship with Collembola and other soil microarthropods.

In jhumland ecosystem, the soil moisture content at 0-10cm showed positive and significant relationship with Acarina ($r = 0.8515$, $p < 0.05$), Collembola ($r = 0.8494$, $p < 0.05$), and others soil microarthropods ($r = 0.8815$, $p < 0.05$). In the soil layer 10-20cm, it showed positive and significant relationship with Acarina ($r = 0.8184$,$p < 0.05$), soil microarthropods ($r = 0.7200$, $p < 0.05$) but insignificant relationship with Collembola ($r = 0.5199$, p

< 0.05), and other microarthropods (r = 0.7200, p < 0.05).At the soil layer 20-30cm, it showed positive and significant relationship with Acarina (r = 0.6394, p < 0.05), Collembola (r = 0.5783, p < 0.05) but only significant negative correlationship with other soil microarthropods (r = - 0.4340, p < 0.05).

Effect of rainfall

In forest ecosystem, it was observed that rainfall was correlated positively and showed significant correlation with Acarina (r = 0.9498, p < 0.05), Collembolla (r = 0.9475, p < 0.05) and other soil microartropods (r = 0.9375, p < 0.05) respectively.

In jhumland ecosystem, it was observed that rainfall was correlated positively and showed significant correlation with Acarina (r = 09606, p < 0.05), Collembola (r = 0.9567, p < 0.05), and others soil microarthropods (r = 0. 0.9358, p < 0.05) respectively.

Effect of Humidity

In forest ecosystem, it was observed that the humidity recorded showed positive and significant correlationship among the Acarina (r = 0.8158, p < 0.05) Collembola (r = 0.7076, p < 0.05) and other microarthropods (r = 0.8780, p < 0.05) respectively.

In jhumland ecosystem, the humidity showed positive and significant correlationship among the Acarina (r = 0.8859, p < 0.05) Collembola (r = 0.8298, p < 0.05) and other microarthropods (r = 0.8576, p < 0.05) respectively.

Effect of soil temperature

In forest ecosystem, it was observed that the soil temperature at 0-10cm showed positive and significant correlationship with Acarina (r = 0.6344, p < 0.05), Collembolla (r = 0.6244, p < 0.05) and other soil microartropods (r =

0.7066, $p < 0.05$). At 10-20cm soil layer, it negative correlationship with Acarina ($r = 0.4635$, $p < 0.05$), but showed positive and significant correlationship with Collembolla ($r = 0.7680$, $p < 0.05$) and other soil microartropods ($r = 0.7799$, $p < 0.05$). At the soil layer 20-30cm, it showed insignificant correlationship with Acarina ($r = 0.5499$, $p < 0.05$), but showed positive and significant correlationship with Collembolla ($r = 0.7361$, $p < 0.05$) and other soil microartropods ($r = 0.8303$, $p < 0.05$) respectively.

In jhumland ecosystem, the soil temperature at 0-10cm showed insignificant correlationship with Acarina ($r = 0.5410$, $p < 0.05$), Collembola ($r = 0.6244$, $p < 0.05$), and others soil microarthropods ($r = 0.6276$, $p < 0.05$). In the soil layer 10-20cm, it showed positive and significant relationship with Acarina ($r = 0.6575$, $p < 0.05$), Collembola ($r = 0.6387$, $p < 0.05$) and other soil microarthropods ($r = 0.6764$, $p < 0.05$). At the soil layer 20-30cm, it showed positive and significant relationship with Acarina ($r = 0.6877$, $p < 0.05$), Collembola ($r = 0.8435$, $p < 0.05$) and other soil microarthropods ($r = 0.7055$, $p < 0.05$) respectively.

Effect of pH

In forest ecosystem, it was observed that the pH at 0-10cm showed positive and significant correlationship with Acarina ($r = 0.6579$, $p < 0.05$), Collembolla ($r = 0.7466$, $p < 0.05$) and other soil microartropods ($r = 0.6878$, $p < 0.05$). At 10-20cm soil layer, positive and significant correlationship with Acarina ($r = 0.7381$, $p < 0.05$), other soil microarthropods ($r = 0.7625$, $p < 0.05$) but insignificant correlationship with Collembolla ($r = 0.5265$, $p < 0.05$) only. At the soil layer 20-30cm, it showed positive and significant correlationship with Acarina ($r = 0.6588$, $p < 0.05$), but showed insignificant correlationship with Collembolla ($r = 0.4009$, $p < 0.05$) and negative correlationship with other soil microarthropods ($r = -0.4757$, $p < 0.05$) respectively.

In jhumland ecosystem, the pH at 0-10cm showed significant negative correlationship with Acarina ($r = -0.5266$, $p < 0.05$) but significant positive

correlationship with Collembola ($r = 0.5787$, $p < 0.05$) and others soil microarthropods ($r = 0.1020$, $p < 0.05$). In the soil layer 10-20cm, it showed significant positive correlationship with Acarina ($r = 0.7381$, $p < 0.05$), Collembola ($r = 0.0513$, $p < 0.05$) and other soil micro arthropods ($r = 0.6959$, $p < 0.05$). At the soil layer 20-30cm, it showed significant positive correlationship with Acarina ($r = 0.6724$, $p < 0.05$) but showed negative correlation with Collembola ($r = -0.3646$, $p < 0.05$) and other soil microarthropods ($r = -0.3923$, $p < 0.05$) respectively.

Effect of Total nitrogen

In forest ecosystem, it was observed that the total soil nitrogen at 0-10 cm showed significant positive correlationship with Acarina ($r = 0.7748$, $p < 0.05$), Collembolla ($r = 0.8456$, $p < 0.05$) and other soil microartropods ($r = 0.7742$, $p < 0.05$). At 10-20cm soil layer, significant positive correlationship with Acarina ($r = 0.7058$, $p < 0.05$), Collembolla ($r = 0.5552$, $p < 0.05$), other soil microarthropods ($r = 0.7507$, $p < 0.05$) only. At the soil layer 20-30cm, it showed significant positive correlationship with Acarina ($r = 0.7102$, $p < 0.05$), Collembolla ($r = 0.6197$, $p < 0.05$) and insignificant correlationship with other soil microarthropods ($r = 0.5304$, $p < 0.05$) respectively.

In jhumland ecosystem, the total soil nitrogen at 0-10 cm showed significant positive correlationship with Acarina ($r = 0.6339$, $p < 0.05$), Collembola ($r = 0.5925$, $p < 0.05$) and others soil microarthropods ($r = 0.6987$, $p < 0.05$). In the soil layer 10-20cm, it showed significant positive correlationship with Acarina ($r = 0.6081$, $p < 0.05$), Collembola ($r = 0.5417$, $p < 0.05$) and other soil microarthropods ($r = 0.6083$, $p < 0.05$). At the soil layer 20-30cm, it showed significant positive correlationship with Acarina ($r = 0.6737$, $p < 0.05$) but showed negative correlation with Collembola ($r = -0.4732$, $p < 0.05$) and other soil microarthropods ($r = -0.3763$, $p < 0.05$) respectively.

Effect of Potassium

In forest ecosystem, it was observed that the potassium at 0-10 cm soil layers showed significant negative correlation with Acarina ($r = - 0.5231$, $p < 0.05$) and other soil microarthropods ($r = - 0.1258$, $p < 0.05$) but significant positive with Collembolla ($r = 0.5517$, $p < 0.05$). At 10-20cm soil layer, significant negative correlationship with Acarina ($r = -0.5460$, $p < 0.05$), Collembolla ($r = - 0.2511$, $p < 0.05$), other soil microarthropods ($r = -0.3069$, $p < 0.05$) only. At the soil layer 20-30cm, it showed significant positive correlationship with Acarina ($r = 0.6368$, $p < 0.05$) and significant negative correlationship with Collembolla ($r = - 0.3432$, $p < 0.05$) and other soil microarthropods ($r = - 0.0998$, $p < 0.05$) respectively.

In jhumland ecosystem, the potassium at 0-10 cm showed significant negative correlationship with Acarina ($r = - 0.5151$, $p < 0.05$), Collembola ($r = - 0.4236$, $p < 0.05$) and others soil microarthropods ($r = - 0.4655$, $p < 0.05$). In the soil layer 10-20cm, it showed significant negative correlationship with Acarina ($r = - 0.2808$, $p < 0.05$) and other soil microarthropods ($r = - 0.2312$, $p < 0.05$) but significant positive correlation with Collembola ($r = 0.5579.$, $p < 0.05$). At the soil layer 20-30cm, it showed significant negative correlationship with Acarina ($r = - 0.3495$, $p < 0.05$), Collembola ($r = - 0.3056$, $p < 0.05$) and other soil microarthropods ($r = - 0.2312$, $p < 0.05$) respectively.

Effect of Phosphorus

In forest ecosystem, it was observed that the phosphorus at 0-10 cm soil layers showed insignificant positive correlation with Acarina ($r = -0.3252$, $p <0.05$) but negative correlation with Collembolla ($r= - 0.3032$, $p < 0.05$) and other soil microarthropods ($r = - 0.2981$, $p < 0.05$). At 10-20 cm soil layer, significant negative correlationship with Acarina ($r = - 0.4863$, $p < 0.05$), Collembolla ($r = - 0.0372$, $p < 0.05$),other soil microarthropods ($r = - 0.6433$, $p < 0.05$) only. At the soil layer 20-30cm, it showed significant negative correlationship with Acarina ($r = - 0.3544$, $p < 0.05$), Collembolla ($r = -$

0.1071, $p < 0.05$) and other soil microarthropods ($r = - 0.0808$, $p < 0.05$) respectively.

In jhumland ecosystem, the phosphorus at 0-10 cm soil layers showed significant negative correlation with Acarina ($r = - 0.3019$, $p < 0.05$), Collembolla ($r = - 0.2260$, $p < 0.05$) and other soil microarthropods ($r = - 0.2259$, $p < 0.05$). At 10-20cm soil layer, significant negative correlationship with Acarina ($r = - 0.0603$, $p < 0.05$), Collembolla ($r = -0.1761$, $p < 0.05$), other soil microarthropods ($r = - 0.1532$, $p < 0.05$) only. At the soil layer 20-30cm, it showed significant negative correlationship with Acarina ($r = - 0.6976$, $p < 0.05$) and other soil microarthropods ($r = - 0.4231$, $p < 0.05$) but significant positive correlationship with Collembolla ($r = 0.5315$, $p < 0.05$) respectively.

Effect of Organic carbon

In forest ecosystem, it was observed that the soil organic carbon at 0-10 cm showed significant positive correlationship with Acarina ($r = 0.6509$, $p < 0.05$), Collembolla ($r = 0.6084$, $p < 0.05$) and other soil microartropods ($r = 0.5363$, $p < 0.05$). At 10-20cm soil layer, significant positive correlationship with Acarina ($r = 0.8296$, $p < 0.05$), Collembolla ($r = 0.5705$, $p < 0.05$), other soil microarthropods ($r = 0.6968$, $p < 0.05$) only. At the soil layer 20-30cm, it showed significant positive correlationship with Acarina ($r = 0.7771$, $p < 0.05$), Collembolla ($r = 0.4876$, $p < 0.05$) and negative correlationship with other soil microarthropods ($r = - 0.0309$, $p < 0.05$).

In jhumland ecosystem, the total soil nitrogen at 0-10 cm showed significant positive correlationship with Acarina ($r = 0.5496$, $p < 0.05$), Collembola ($r = 0.5920$, $p < 0.05$) and others soil microarthropods ($r = 0.6916$, $p < 0.05$). In the soil layer 10-20cm, it showed significant positive correlationship with Acarina ($r = 0.7981$, $p < 0.05$), Collembola ($r = 0.8292$, $p < 0.05$) and other soil microarthropods ($r = 0.9043$, $p < 0.05$). At the soil layer 20-30cm, it showed significant positive correlationship with Acarina ($r =$

0.8118, $p < 0.05$), Collembola ($r = -0.6892$, $p < 0.05$) and other soil microarthropods ($r = 0.5496$, $p < 0.05$) respectively.

Table 10: Corelationships between Acarina and physical factors

Factors	Soil layers (cm)	Forest ecosysytem			Jhumland ecosystem		
		r^2	r	p	r^2	r	p
Soil moisture (%)	0-10	58.09	0.76	p< 0.05	72.51	0.85	p< 0.05
	10-20	65.60	0.80	p< 0.05	66.98	0.81	p< 0.05
	20-30	52.94	0.72	p< 0.05	40.88	0.63	p< 0.05
Soil temp (^{0}C)	0-10	40.24	0.63	p< 0.05	29.27	0.54	p< 0.05
	10-20	21.49	-0.46	p< 0.05	43.23	0.65	p< 0.05
	20-30	30.74	0.54	p< 0.05	47.30	0.68	p< 0.05
Rainfall (cm)	0-30	90.21	0.94	p< 0.05	92.27	0.96	p< 0.05
Humidity (%)	0-30	72.55	0.81	p< 0.05	78.48	0.88	p< 0.05

Table 11: Corelationships between Collembola and physical factors

Factors	Soil layers (cm)	Forest ecosysytem			Jhumland ecosystem		
		r^2	r	p	r^2	r	p
Soil moisture (%)	0-10	60.73	0.77	p< 0.05	72.16	0.84	p< 0.05
	10-20	8.29	-0.28	p< 0.05	27.03	0.51	p< 0.05
	20-30	6.26	-0.25	p< 0.05	33.44	0.57	p< 0.05
Soil temp (^{0}C)	0-10	39.99	0.62	p< 0.05	38.99	0.62	p< 0.05
	10-20	58.98	0.76	p< 0.05	40.80	0.63	p< 0.05
	20-30	54.19	0.73	p< 0.05	71.15	0.84	p< 0.05
Rainfall (cm)	0-30	89.77	0.94	p< 0.05	91.53	0.95	p< 0.05
Humidity (%)	0-30	50.07	0.70	p< 0.05	68.86	0.82	p< 0.05

Table 12: Correlationship between other soil microarthropods and physical factors

Factors	Soil layers (cm)	Forest ecosysytem			Jhumland ecosystem		
		r^2	r	p	r^2	r	p
Soil moisture (%)	0-10	52.61	0.72	p< 0.05	77.71	0.88	p< 0.05
	10-20	35.67	0.59	p< 0.05	51.84	0.72	p< 0.05
	20-30	1.52	-0.12	p< 0.05	18.83	-0.43	p< 0.05
Soil temp (^{0}C)	0-10	49.93	0.70	p< 0.05	38.99	0.62	p< 0.05
	10-20	60.83	0.77	p< 0.05	45.75	0.67	p< 0.05
	20-30	68.95	0.83	p< 0.05	49.78	0.70	p< 0.05
Rainfall (cm)	0-30	87.88	0.93	p< 0.05	87.58	0.93	p< 0.05
Humidity (%)	0-30	77.09	0.87	p< 0.05	73.55	0.85	p< 0.05

Table 13: Correlationship between Acarina and chemical factors

Factors	Soil layers (cm)	Forest ecosysytem			Jhumland ecosystem		
		r^2	r	p	r^2	r	p
Soil pH	0-10	43.28	0.65	p< 0.05	27.73	-0.52	p< 0.05
	10-20	54.47	0.73	p< 0.05	54.47	0.73	p< 0.05
	20-30	43.40	0.65	p< 0.05	45.21	0.67	p< 0.05
Soil total nitrogen (%)	0-10	60.04	0.77	p< 0.05	40.19	0.63	p< 0.05
	10-20	49.82	0.70	p< 0.05	36.98	0.60	p< 0.05
	20-30	50.45	0.71	p< 0.05	45.39	0.67	p< 0.05
Soil potassium (%)	0-10	27.36	-0.52	p< 0.05	26.53	-0.51	p< 0.05
	10-20	29.82	-0.54	p< 0.05	7.88	-0.28	p< 0.05
	20-30	40.43	0.63	p< 0.05	12.21	-0.34	p< 0.05
Soil available Phosphorus (%)	0-10	23.65	-0.32	p< 0.05	10.59	-0.30	p< 0.05
	10-20	10.58	-0.48	p< 0.05	0.36	-0.06	p< 0.05
	20-30	12.56	-0.35	p< 0.05	2.73	-0.69	p< 0.05
Soil organic carbon (%)	0-10	42.36	0.65	p< 0.05	30.20	0.54	p< 0.05
	10-20	68.82	0.82	p< 0.05	63.69	0.79	p< 0.05
	20-30	60.39	0.77	p< 0.05	65.91	0.81	p< 0.05

Table 14: Correlationship between Collembola and chemical factors

Factors	Soil layers (cm)	Forest ecosysytem			Jhumland ecosystem		
		r^2	r	p	r^2	r	p
Soil pH	0-10	55.66	0.74	p< 0.05	33.48	0.57	p< 0.05
	10-20	27.42	0.52	p< 0.05	32.68	0.05	p< 0.05
	20-30	16.08	0.40	p< 0.05	13.29	-0.36	p< 0.05
Soil total nitrogen (%)	0-10	71.51	0.84	p< 0.05	35.10	0.59	p< 0.05
	10-20	30.82	0.55	p< 0.05	29.35	0.54	p< 0.05
	20-30	38.41	0.61	p< 0.05	22.39	-0.47	p< 0.05
Soil potassium (%)	0-10	30.43	0.55	p< 0.05	17.95	-0.42	p< 0.05
	10-20	6.31	-0.25	p< 0.05	23.89	0.57	p< 0.05
	20-30	11.78	-0.34	p< 0.05	9.34	-0.30	p< 0.05
Soil available Phosphorus (%)	0-10	9.20	-0.30	p< 0.05	5.11	-0.22	p< 0.05
	10-20	0.14	-0.03	p< 0.05	3.10	-0.17	p< 0.05
	20-30	1.56	-0.10	p< 0.05	28.25	0.53	p< 0.05
Soil organic carbon (%)	0-10	37.02	0.60	p< 0.05	35.04	0.59	p< 0.05
	10-20	32.55	0.57	p< 0.05	68.76	0.82	p< 0.05
	20-30	23.78	0.48	p< 0.05	47.50	0.68	p< 0.05

Table 15: Correlationship between other microarthropods and chemical factors

Factors	Soil layers (cm)	Forest ecosysytem			Jhumland ecosystem		
		r^2	r	p	r^2	r	p
Soil pH	0-10	47.31	0.68	p< 0.05	42.38	0.65	p< 0.05
	10-20	52.78	0.72	p< 0.05	47.04	0.69	p< 0.05
	20-30	22.63	-0.47	p< 0.05	15.39	-0.39	p< 0.05
Soil total Nitrogen (%)	0-10	59.94	0.77	p< 0.05	48.81	0.69	p< 0.05
	10-20	56.36	0.75	p< 0.05	37.00	0.60	p< 0.05
	20-30	28.13	0.53	p< 0.05	14.16	-0.37	p< 0.05
Soil potassium (%)	0-10	21.81	0.12	p< 0.05	21.67	-0.46	p< 0.05
	10-20	9.42	-0.30	p< 0.05	18.60	-0.43	p< 0.05
	20-30	1.00	-0.09	p< 0.05	5.35	-0.23	p< 0.05
Soil available Phosphorus (%)	0-10	8.89	-0.29	p< 0.05	5.10	-0.22	p< 0.05
	10-20	2.23	-0.64	p< 0.05	2.35	-0.15	p< 0.05
	20-30	0.65	-0.08	p< 0.05	17.90	-0.42	p< 0.05
Soil organic carbon (%)	0-10	28.76	0.53	p< 0.05	47.84	0.69	p< 0.05
	10-20	48.55	0.69	p< 0.05	81.78	0.90	p< 0.05
	20-30	9.60	-0.03	p< 0.05	30.20	0.54	p< 0.05

Table 16: Correlationship between total soil microarthropods and physical factors

Factors	Soil layers (cm)	Forest ecosysytem			Jhumland ecosystem		
		r^2	r	p	r^2	r	p
Soil moisture (%)	0-10	58.09	0.76.22	p< 0.05	62.38	0.78	p< 0.05
	10-20	57.22	0.7564	p< 0.05	55.26	0.74	p< 0.05
	20-30	52.66	0.7257	p< 0.05	51.57	0.71	p< 0.05
Soil temp (^{0}C)	0-10	40.24	0.6344	p< 0.05	28.07	0.52	p< 0.05
	10-20	39.31	0.6270	p< 0.05	25.92	0.50	p< 0.05
	20-30	36.99	0.6282	p< 0.05	25.54	0.50	p< 0.05
Rainfall (cm)	0-30	92.27	0.9606	p< 0.05	86.09	0.92	p< 0.05
Humidity (%)	0-30	72.55	0.8518	p< 0.05	75.41	0.86	p< 0.05

Table 17: Correlationship between total microarthropods and chemical factors

Factors	Soil layers (cm)	Forest ecosysytem			Jhumland ecosystem		
		r^2	r	p	r^2	r	p
Soil pH	0-10	42.28	0.65	p< 0.05	44.45	0.66	p< 0.05
	10-20	20.21	0.44	p< 0.05	79.95	0.89	p< 0.05
	20-30	46.40	0.68	p< 0.05	24.95	0.64	p< 0.05
Soil total Nitrogen (%)	0-30	60.04	0.77	p< 0.05	52.45	0.72	p< 0.05
Soil potassium (%)	0-10	27.36	-0.52	p< 0.05	24.42	-0.49	p< 0.05
Soil available Phosphorus (%)	0-10	10.50	-0.32	p< 0.05	15.21	-0.39	p< 0.05
Soil organic carbon (%)	0-10	59.42	0.77	p< 0.05	79.35	0.89	p< 0.05

In the present study conducted, the physico-chemical factors showed positive significant correlation with the density of soil microarthropods population in both the forest and jhumland ecosysytem. The density of Acarina population was higher followed by Collembola and other soil microarthropods. The positive correlation between microarthropods and soil moisture content reported by Dhuri, *et al*. (1978), Kaczmarek (1975), Nijima (1975), Price (1973). The positive relationships between Acarina and soil moisture content established across a range of ecosystems reported by Lindberg *et al*. (2002), Badejo and Akinwole (2006), Chikoski *et al.*, (2006), Classen *et al.*, (2006) showed that Acarina might be adapted to strong seasonal fluctuations in soil moisture content in the forest and jhumland ecosystem. Choi *et al.*, (2002) reported that temperature and moisture are two of the most important environmental factors affecting populations of soil microarthropods. The density of the soil microarthropods decreased with the soil depth from 0-10 cm, 10-20 cm to 20-30 cm in both the two ecosystem which might be the fragmentation and mineralisation process during decomposition of litter material, resulting in homogenisation of soil organic matter with increasing depth, reduced habitat complexity and reduced resource quality indicating lower availability of resources. The increase in soil moisture content showed increase in the density of the soil microarthropods and Acarina are generally supported in the upper layer of the soil at 0-10 cm which provides a conducive micro-environment as reported by Badejo, and Akintola (2006). The density of population has been decreased in the jhumland ecosystem due to the “slash and burn’’ practices where land preparation, furrow opening, preparation of ridges etc disturbed the habitat of the soil microarthropods. Hansen (2000) observed that the higher degree of disturbance, vegetation covers and sudden changed environmental conditions directly affect the microarthropods population.

In both the two ecosystem, the pH showed positive correlation with the soil microarthropods with decreased pH level, leading to lower diversity and abundance of soil fauna reported by Teuben and Smidt (1992). In the forest ecosystem, the soil microarthropods population was found higher consisting of rich nutrient habitat, moist and suitable soil environment. Loreau *et al*., (2001)

while working on biodiversity and ecosystem functioning observed that harsh climatic conditions could lead to gradual losses of species specific and such losses could be random with respect to species effect on any given ecosystem processes, leading to patterns of process response to changes in diversity similar to those observed in randomly assembled communities.

During the study, it was observed that positive significant relationship between pH, organic carbon and total nitrogen with all soil microarthropods in both the two ecosystems. But insignificant relationship was shown between potassium and phosphorus with all other soil microarthropods. Duolo (2007) observed that negative correlationship between organic carbon, total nitrogen, available P and K with soil microarthropods in natural forest ecosystem and reverse in degraded forest ecosystem. Positive correlationship was observed in organic carbon with Acarina population but negative correlation with temperature, pH, moisture and phosphate by Maitra (1987). The soil pH showed positive and significant relationship among the soil arthropods in both the two ecosystems. Cancela da Fonseca *et al*, (1995) reported that the soil pH had greater influence on the soil microarthropods abundance than the soil temperature or moisture. In the ecosysytems, the total nitrogen and the soil microarthropods was positively correlated. Seastedt (1984) observed that soil fauna enhance nitrogen mineralization markedly by up to 25%. Seastedt and Crossley (1983) reported the effect of substrate communition are major phenomena in forest ecosystem where a large fraction of mass loss can be attributed directly or indirectly to the presence of fauna and the importance of faunal activities is greater with recalcitrant substrates. The effect of fauna on decomposition rates was higher in forest ecosystem. Seastedt (1984) observed that the flow of decomposition rate has been well demonstrated in the forest ecosystem but not in agro-ecosystem. In jhumland ecosystem, the effect of fauna on decomposition rates appears to be lesser significance. Many crops residues are higher in nitrogen, lower in lignin and may decompose more rapidly than the forest leaf litter awing to direct microbial attack. Cromack *et al*. (1975) observed that the effect of soil fauna on nutrients dynamics and calcium dynamics remain undemonstrated in agro-ecosystem, although they contain number of oribatid mites (Acarina) which are important in the calcium

dynamics of forest ecosystem. The effect of soil fauna on nutrient cycling in agro-ecosystem may be of particular importance in reducing fertilization schedules by increasing the use efficiency of fertilizer input.

In the present study conducted, most of the findings were similar to earlier workers except few insignificant observations may vary in certain cases. Differences in observations may vary from plot to plots due to local microclimatic factors as reported by Wallwork (1970). Few factors responsible for the soil microarthropods densities at higher altitudes especially to the two ecosystem may be because of higher soil acidity, harsh abiotic conditions, high densities of macroarthropods and lower quantity of resources.

Community analysis of acarina and collembola

Oribatids (Acari: Oribatei) and collembolans (Insecta: Collembola) are small arthropods (body size of 0.2 - 2.0mm) which live a free existence, mainly in soil but not infrequently in wet biotopes. These soil animals are widely distributed around the world, playing a biological role of great importance both in natural and agricultural ecosystems, Oribatid mites and collembolans form the main part of soil microarthropods in terms of number of individuals and species. Vertically the total soil microarthropod diversity was found to be the highest in the 0-10 cm soil layer and gradually decreasing with increase in soil depth showing a minimum in the 20-30 cm layer.

In the present investigation a total of 1241.55 x 10^2 m^{-2} and 677.80 x 10^2 m^{-2} soil microarthropods were recorded from forest and jhumland ecosystem respectively. In the uppermost layer i.e. 0-10 cm, the total microarthropods density was recorded to be 473.08 x 10^2 m^{-2} and 371.10 x 10^2 m^{-2} in the forest and jhumland respectively. While at 10-20 cm soil layer 324.23 x 10^2 m^{-2} and 221.56 x 10^2 m^{-2} of soil microarthropods was recorded. The 20-30 cm soil layer constitutes minimum density of 234.56 x 10^2 m m^{-2} and 97.72 x 10^2 m^{-2} in forest and jhumland ecosystem respectively.

Among the total soil microarthropods of thirty (30) species identified in the present investigation (Photo plate nos.), Acarina was the most dominant group contributing 43.38 % of the total soil microarthropod population out of which only twenty (20) different species were identified. Collembola was the second major groups and contributed 23.13 - 29.72% to the total soil microarthropod population.

The smaller minor groups like Myriapoda, Hymenoptera, Diplura and Protura are represented by few individual species (Plate no. 44 to 50) in both the study sites. They altogether contributed 23.41% and 26.11% to the total soil microarthropods in forest and jhumland ecosystem respectively. The remaining soil microarthropods were designated as other soil microarthropods and represented Pseudoscorpion, Homoptera, Spider and other insect larvae,

contributing 8.36% and 9.12 % to the total soil microarthropods in forest and jhumland ecosystem respectively.

Community analysis was carried out only for two major groups of soil microarthropods i.e. Acarina and Collembola in the present study as their contributions are maximum in term of species, abundance and distribution. This is also the reason why the two groups are often combined in soil ecological studies as "microarthropods". A total of thirty (30) different species with fifteen (15) species in each group (Acarina & Collembola) were identified from the two study sites i.e. forest and jhumland ecosystem.

The two sites showed different physico-chemical properties of soil as well as microclimatic conditions, therefore analysis was done to find the species richness, diversity and distribution patterns of Acarina and Collembola community between the two sites. The species diversities and similarities of the communities were analyzed using the following indices of Margalefs index (Da) (1968), Shannon-Wiener index (H') (1949), Sorensen's index (Q/S) of similarity (1948), Average faunal resemblance and evenness or equitability index (Pielou, 1969).

Community analysis of Collembola

The species of Collembola found in the forest ecosystem are as follows, *Cyphoderus albinos*, *Entomobrya triangularis*, *Entomobrya clitellaria*, *Isotomodes productus*, *Isotomurus unifasciatus*, *Lepidocyrtus kauriensis*, *Lepidocyrtus curvicollis*, *Lepidocyrtus rataensis*, *Odontella minutudentata*, *Proisotoma subminuta*, *Pseudofolsomia sp*, *Pseudosinella orba*, *Pachytullbergia scabra*, *Scutisotoma millimetrica*,*Weberacantha, sp*.

The Collembola species found in the jhumland ecosystem are as follows, *Bourletiella arvalis*, *Dicyrtoma melitensis*, *Deuterosminthurus pallipes*, *Entomobrya clitellaria*, *Entomobrya triangularis*, *Isotomodes productus*, *Isotomeilla minor*, *Pseudofolsomia sp*, *Proisotoma subminuta*,

Lepidocyrtus kauriensis, Lepidocyrtus rataensis, Pseudosinella orba, Pachytullbergia scarab, Scutisotoma millimetrica, Weberacantha sp.

Table 18: Species diversity of the total indentified Collembola in different seasons at 0-10cm soil depth in forest ecosystem.

Season	Margalef's Index (Da)	Diversity(H')	Hmax'
Summer	8.246	3.775	3.344
Rainy	7.552	3.221	3.558
Winter	6.533	2.885	2.735

Table 19: Species diversity of the total identified Collembola in different seasons at 10-20cm soil depth in forest ecosystem.

Season	Margalef's Index (Da)	Diversity(H')	Hmax'
Summer	7.991	3.595	3.441
Rainy	7.323	3.353	3.237
Winter	5.626	2.336	2.587

Table 20: Species diversity of the total identified Collembola in different seasons at 20 -30 cm soil depth in forest ecosystem.

Season	Margalef's Index (Da)	Diversity(H')	Hmax'
Summer	6.557	3.325	3.444
Rainy	7.224	3.651	4.000
Winter	4.616	3.215	3.101

Table 21: Species diversity of the total indentified Collembola in different seasons at 0-10cm soil depth in jhumland ecosystem.

Season	Margalef's Index (Da)	Diversity(H')	Hmax'
Summer	7.443	3.875	3.751
Rainy	7.112	3.550	3.661
Winter	5.636	3.664	3.223

Table 22: Species diversity of the total indentified Collembola in different seasons at 10 -20cm soil depth in jhumland ecosystem.

Season	Margalef's Index (Da)	Diversity(H')	Hmax'
Summer	7.113	3.993	3.622
Rainy	6.995	3.000	3.229
Winter	5.312	2.887	2.773

Table 23: Species diversity of the total identified Collembola in different seasons at 20-30cm soil layers in jhumland ecosystem.

Season	Margalef's Index (Da)	Diversity(H')	Hmax'
Summer	6.335	3.559	3.559
Rainy	6.223	3.441	3.636
Winter	5.000	3.111	3.005

Data analysis of Collembola (Table) using Margalefs index (Da) and Shannon Wiener diversity index (H') have shown more diversity in the forest than jhumland ecosystem. In forest ecosystem, maximum value of diversity (Da = 8.246, H' = 3.993) was shown during rainy and summer seasons and minimum during winter season. While in jhumland ecosystem, maximum value of diversity (Da = 7.433, H' = 3.225) were recorded in summer season.

Hmax' of Collembola was found to be higher in forest ecosystem as compared with jhumland ecosystem. In forest ecosystem, Hmax' value was highest in rainy season (4.000) and lowest in winter seasons (2.587) respectively. While in jhumland ecosystem, Hmax' value was highest in rainy season (3.751) and lowest in winter (2.773) respectively.

The higher diversity indices in both the study sites have been recorded higher during summer and rainy season in all the soil layer i.e. at 0-10 cm, 10-20cm and 20-30cm. While lesser diversity indices have recorded during winter season in both the study sites in all the soil layers. The Hmax' i.e. the

maximum diversity was also recorded with higher value in summer and rainy season than winter season in all the soil layers.

Table 24: Distribution of Collembola species in different seasons of forest ecosystem.

Sl.No	Species	Summer	Rainy season	Winter
1	*Cyphoderus albinos*	High	Moderate	Absent
2	*Entomobrya triangularis*	Moderate	Absent	Absent
3	*Entomobrya clitellaria*	High	Moderate	Absent
4	*Isotomodes productus*	Moderate	High	Absent
5	*Isotomurus unifasciatus*	Absent	High	Low
6	*Lepidocyrtus kauriensis*	Moderate	Moderate	Moderate
7	*Lepidocyrtus curvicollis*	Moderate	High	Absent
8	*Lepidocyrtus rataensis*	Moderate	High	Absent
9	*Odontella minutudentata*	Absent	High	Moderate
10	*Proisotoma subminuta*	Moderate	High	Absent
11	*Pseudofolsomia sp*	Absent	High	Absent
12	*Pseudosinella orba*	Moderate	High	Absent
13	*Pachytullbergia scabra*	Moderate	Moderate	High
14	*Scutisotoma millimetrica*	Moderate	Absent	Absent
15	*Weberacantha*	Absent	Moderate	High

Table 25: Distribution of Collembola species in different seasons of jhumland ecosystem

Sl.No	Species	Summer	Rainy season	Winter
1	*Entomobrya clitellaria*	Absent	Moderate	Absent
2	*Isotomodes productus*	High	High	Absent
3	*Isotomeilla minor*	Absent	High	Absent
4	*Pseudofolsomia sp.*	Absent	Moderate	Absent
5	*Proisotoma subminuta*	Abundant	Absent	High
6	*Lepidocyrtus kauriensis*	Moderate	Moderate	Absent
7	*Lepidocyrtus rataensis*	Moderate	High	Moderate
8	*Pseudosinella orba*	Absent	Moderate	Absent
9	*Pachytullbergia scabra*	Moderate	High	Absent
10	*Bourletiella arvalis*	Absent	Absent	Moderate
11	*Dicyrtoma melitensis*	Moderate	Moderate	Absent
12	*Deuterosminthurus pallipes*	Absent	High	Absent
13	*Weberacantha*	High	Moderate	absent
14	*Scutisotoma millimetrica*	Moderate	Absent	Absent
15	*Entomobrya triangularis*	Moderate	Absent	absent

Community analysis of Acarina

Fifteen different species of Acarina were found in the two study sites, they are as follows, *Allosuctobella sp., Bdella sp.(2), Cosmozercon sp., Dendrohermannia sp. (2), Gamasellus sp., Haplozetes sp., Limnozetes sp.,*

Nothrus palustrus, Olalaelaps sp., Oribotritia sp., Pergalumna sp., Robustocheles sp., Tectocephus sp., Uropoda cassidea.

Table 26: Species diversity of the total indentified Acarina in different seasons at 0-10cm soil depth in forest ecosystem.

Season	**Margalef's Index (Da)**	**Diversity(H')**	**Hmax'**
Summer	5.668	3.315	3.445
Rainy	4.965	3.682	3.228
Winter	5.354	3.772	3.635

Table 27: Species diversity of the total identified Acarina in different seasons at 10-20cm soil depth in forest ecosystem.

Season	**Margalef's Index (Da)**	**Diversity(H')**	**Hmax'**
Summer	5.882	2.195	2.541
Rainy	5.231	2.953	2.407
Winter	5.325	3.121	2.113

Table 28: Species diversity of the total identified Acarina in different seasons at 20 – 30 cm soil depth in forest ecosystem.

Season	**Margalef's Index (Da)**	**Diversity(H')**	**Hmax'**
Summer	5.342	3.325	4.164
Rainy	6.335	3.651	4.091
Winter	6.617	3.215	4.951

Table 29 : Species diversity of the total indentified Acarina in different seasons at 0-10cm soil depth in jhumland ecosysystem.

Season	**Margalef's Index (Da)**	**Diversity(H')**	**Hmax'**
Summer	3.343	2.011	2.428
Rainy	4.128	2.528	2.171
Winter	3.665	2.658	2.223

Table 30: Species diversity of the total indentified Acarina in different seasons at 10 -20cm soil depth in jhumland ecosystem.

Season	Margalef's Index (Da)	Diversity(H')	Hmax'
Summer	3.559	3.332	2.331
Rainy	4.771	3.143	3.110
Winter	3.325	3.000	2.003

Table 31: Species diversity of the total identified Acarina in different seasons at 20-30cm soil layers in jhumland ecosystem.

Season	Margalef's Index (Da)	Diversity(H')	Hmax'
Summer	4.356	2.447	2.285
Rainy	3.371	2.613	2.311
Winter	3.551	2.530	2.513

Data analysis of Acarina (Table) using Margalefs index (Da) and Shannon-Wiener diversity index (H') have shown more diversity in forest than the jhumland ecosystem. In forest ecosystem, maximum value of diversity (Da = 5.882, H' = 3.682) was shown during summer and rainy season and minimum during winter season. While in jhumland ecosystem, maximum value of diversity (Da = 4.771, H' = 3.332) were recorded in summer season.

Hmax' of Collembola was found to be higher in forest ecosystem as compared with jhumland ecosystem. In forest ecosystem, Hmax' value was highest in rainy season (4.164) and lowest in winter seasons (2.113) respectively. While in jhumland ecosystem, Hmax' value was highest in rainy season (3.110) and lowest in winter (2.003) respectively.

The higher diversity indices in both the study sites have been recorded higher during summer and rainy season in all the soil layer *i.e.*, at 0-10 cm, 10-20cm and 20-30cm. While lower diversity indices have been recorded in all the soil layers, in both the study sites.

Table 32: Distribution of Acarina species in different seasons of forest ecosystem

Sl.No	Species	Summer	Rainy season	Winter
1	*Allosuctobelba sp*	High	High	High
2	*Bdella longicornis*	High	Absent	Absent
3	*Cosmozercon sp*	Absent	Absent	Moderate
4	*Dendrohermannia monstrouse*	Absent	Moderate	Moderate
5	*Gamasellus sp*	Moderate	Moderate	High
6	*Hermannia sp*	Moderate	Moderate	Absent
7	*Haplozetes sp*	High	Moderate	High
8	*Limnozetes palinerae*	Moderate	High	Absent
9	*Nothrus palustrus*	Moderate	High	Low
10	*Ololaelaps sp*	Moderate	Moderate	Absent
11	*Oribotritia sp*	High	High	Moderate
12	*Pergalumna sp*	Moderate	High	Absent
13	*Robustocheles sp*	Moderate	High	High
14	*Tectocepheus sp*	Moderate	Absent	Absent
15	*Uropoda cassidea*	Absent	Moderate	Moderate

Table 33: Distribution of Acarina species in different seasons of jhumland ecosystem

Sl.No	Species	Summer	Rainy season	Winter
1	*Allosuctobelba sp.*	High	High	Moderate
2	*Bdella longicornis*	High	High	Moderate
3	*Dinychus sp.*	Absent	Moderate	High
4	*Hermannia sp.*	High	Moderate	Absent
5	*Haplozetes sp.*	High	High	High
6	*Limnozetes palinerae*	Moderate	High	Absent
7	*Ololaelaps sp*	Moderate	High	Moderate
8	*Oribotritia sp*	Absent	High	Absent
9	*Pergalumna sp*	Moderate	Moderate	Absent
10	*Robustocheles sp*	Absent	Low	Moderate
11	*Tectocepheus sp*	Moderate	Moderate	High
12	*Cosmozercon sp*	Moderate	High	Absent
13	*Gamasellus sp*	High	High	Moderate
14	*Pergalwnna sp.*	Moderate	High	High
15	*Poecilochirus*	Moderate	High	absent

The result from the present investigation indicates that the two study site showed variation in its community structure. Overall the number of individuals, species and the value of diversity were found to be higher and more consistent in the forest ecosystem than that of jhumland ecosystem. It was also seen that some of the species of Acarina and Collembola that were

found in forest ecosystem were totally absent in jhumland which brings about a decrease or disappearance of the least abundant species, while the most abundant species persist (Gurrea *et al.*, 2000).

Margalef s index and Shannon-Wiener diversity index, showed that at different soil layer of different season, the species richness and diversity was higher in forest ecosystem than that of jhumland ecosystem. Aoki (1967) and Asikidis & Stamou (1991) revealed the importance of microhabitats in the distribution of soil microarthropods. The microclimatic conditions, also plays a major role in microarthropod distribution and abundance. Since the forest ecosystem was less disturbed than the jhumland ecosystem, the species diversity and abundance of Collembola, Acarina and other microarthropods were higher than the jhumland ecosystem. Any disturbances are much more resilient in the forest ecosystem which allow microarthropods communities to recover quickly, thus diversity is maintained. According to Whitford and Sobhy (1999) that soil microarthropods were more abundant in below-canopy soils. In forest ecosystem, from the forest floor till tree canopy were so thick that any external factors have least effect over the soil microarthropods community, thus the species richness, diversity and abundance were maintained.

The functioning of terrestrial ecosystems was dependent upon the interrelationships between above-ground and below-ground food webs, and transfer of biotic components of the decomposer subsystem to above ground consumers connect the two subsystems (Johnston and John, 2000). Microarthropods are important components of the soil decomposer food web. Organic matter was a major influence on microarthropods abundance and diversity. The microarthropods community was a positive feedback for improved soil quality. The microarthropods use organic matter, regulate other decomposers in the soil food web and aid in the release of nutrients bound up in residues and microbial biomass (bacteria and fungi) (Lachnicht *et al.*, 2002). Considering the role that microarthropods play in nutrient cycling, determining the functional response of a wide range of taxa to thinning may be important to effective ecosystem management as reported by Peck *et al.*

(2005). Thus diversity at any soil layer was not affected by shortage or because of limited food; instead the endemic species of that particular habitat was maintained and not lost. Therefore, in forest ecosystem because of its wide range in tolerance, soil microarthropods tends to strive better which result into more population density as well as occurrence of more different species showing wider range of species diversity.

In jhumland ecosystem, when compared with that of forest ecosystem have fewer species richness and diversity. From the result, various species diversity indices value indicates loss of species richness which corresponds to loss of biodiversity due human disturbance and activity. This decreased was determined by several factors, among which vegetation was of particular importance. Lower abundance and changes in community composition are likely due to disturbance of the forest floor. Oribatid mite species showed significantly lower abundance in clear cuts than in uncut sites (Lindo *et al.*, 2004). Further several studies have shown a decline in Collembola abundance in response to clear cutting, at least in the short-term (Vlug and Borden, 1973; Huhta, 1976; Bird & Chatarpaul, 1986; Hoekstra *et al.*, 1995; Donegan *et al.*, 2001). In general, it can be stated that there was environmental negative feedback on the soil microarthropods community, which allow only the most abundant, and with wide tolerance species to persist. The abundance of soil microarthropods species in this jhumland ecosystem depends much on the physico-chemical factors of the soil. Since the vegetation is less when compared with forest ecosystem, the organic matter through litters is found to be less abundant which mean the jhumland floor have scarcity of food for microarthropods though their food was not limited only to organic matters. The physical factors such as rainfall, humidity and air temperature were common to both the study sites, therefore it was those factors present within the forest community itself that influence the abundance and diversity of soil microarthropods community. Factors such as absent of tree-canopy, less soil-water retention and continuous disturbances by human activity may be the major hindrance which the forest community cannot sustain itself and changes according to its environmental factors.

Community analysis of Acarina and Collembola populations in both forest and jhumland ecosystem showed maximum abundance, and species diversity in rainy season and slowly decreased in summer and winter seasons. Seasonal differences in the abundance of soil arthropods have been demonstrated by various workers (Salt, 1952; Davis, 1963; Block, 1966; Nijima, 1971; Usher, 1975). These workers reported that microarthropods undergo enormous fluctuations in numbers, these being susceptible to small changes factor influencing population size. Wallwork (1970), Fujikawa (1970) and Anderson (1988) suggest that the temporal pattern has been related to transition from one season to another which was mostly due to shift in soil moisture and temperature.

Soil microarthropods are attributed with regulating many soil processes, including decomposition, mineralization, influencing populations of other soil organisms, energy flow, and nutrient cycling in ecosystems (Petersen and Luxton 1982; Seastedt 1984; Wallwork 1983). Disturbance of soil microarthropod communities has the potential to alter or disrupt these processes. Natural disturbances and anthropogenic alteration of the landscape affect soil microarthropod communities. Fire drastically reduces the numbers of microarthropods (Huhta *et al*., 1967).

Distributions of microarthropods fluctuate seasonally. Populations of microarthropods tend to reach a peak density during the late autumn/early winter months, with the lowest densities occurring during midsummer (Wallwork 1970; Fujikawa 1970a; Anderson 1978). This temporal pattern has been related to soil moisture and temperature: as spring transitions into summer, there is a shift from the wet season to the dry season, a decrease in soil moisture and an increase in soil temperature. In fall, the wet season begins again, increasing soil moisture and decreasing soil temperature (Cancela da Fonseca *et al*. 1995). In colder climates, a drop in temperature during the winter can also result in decreasing population densities (Asikidis and Stamou 1991), creating a second peak of population density during the spring as populations recover. Litterfall has also been identified as an environmental factor influencing the temporal distribution of microarthropods (Santos *et al*., 1978; Luxton, 1983). The preponderance of microarthropod species in realtion to biotic and abiotic (or physic-chemical) factors may be indicative of a close relationship, amongst them.

Soil ecosystems are interconnected by food webs and microarthropods play many roles within that. For example, many are considered to be fungivorous, but there are also predaceous mites in the soil. Collembola, although primarily fungivorous, have been known to feed on roots in the absence of other food sources (Hopkin 1997).

Studying a simple grassland soil food web (Figure 4) illustrates where microarthropods fit into the larger picture of the soil food web. In this soil

food web, the fungivorous mites, nematodes and Collembola feed upon both mycorrhizal and saprotrophic fungi. In a more complex system, such as one that would be found in a forest soil, their diets are probably more complex, including a variety of fungi in different functional groups, such as pathogens, mycorrhizal partners with plants and saprotrophs.

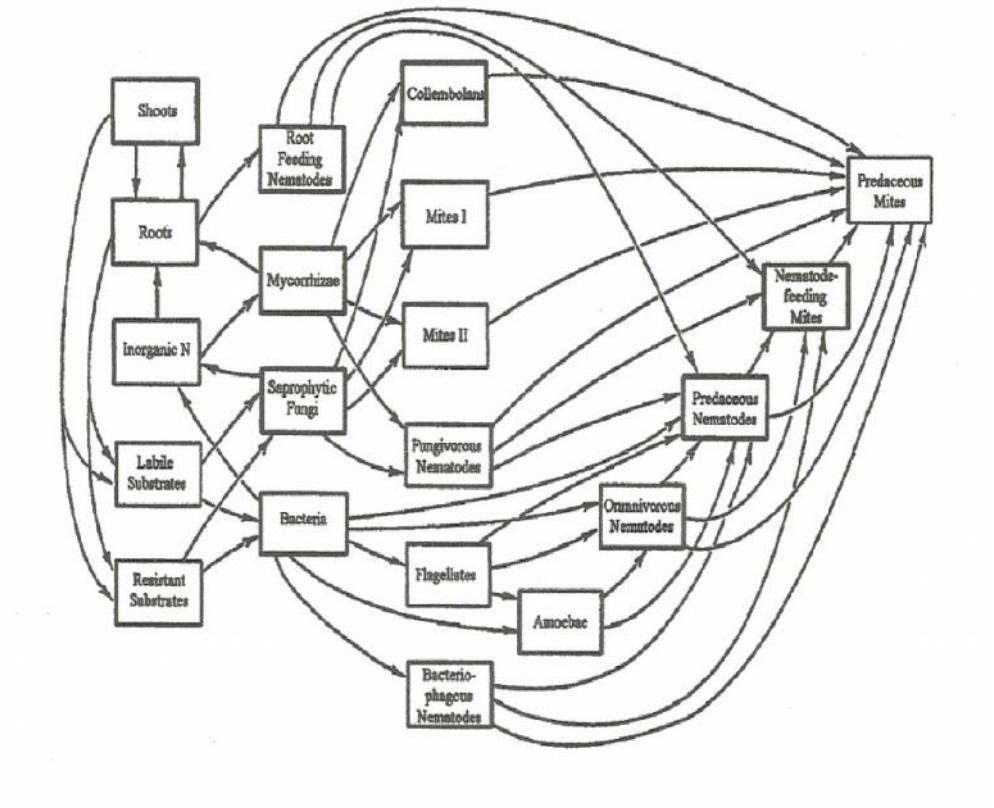


Fig. 52: A simple soil food web according to Elliott *et al*. (1988)

It is important to consider the species-level interaction up and down the food web, particularly to understand the ecology and natural history of a particular fungus, perhaps a common pathogen, or a mycorrhizal associate in the context of forest management or sustainability. If the microarthropod and fungus community are altered, their interactions are altered and this alters the food web.

Feeding differences in the microarthropods may also result in different impacts on the various members of the microbial community. It is therefore,

important to pay attention to this, because different species of fungi may play a variety of roles within the soil community, from saprotrophic decomposers to mycorrhizae to plant pathogens. Evidence from gut content analysis of collembolans and mites indicate that they ingest a variety of amorphous material along with fungal hyphae (Anderson & Healey 1971**;** Behan & Hill 1978).

Their feeding habits have been described by Luxton (1972) as three strategies *viz. microphytophagous*, *macrophytophagous* or *panphytophagous*. Various microarthropod species sometimes show slightly different food preference hierarchies, although there is often overlap between the feeding preferences of different animals (Maraun *et al*., 2003). Differences in feeding habits or preferences may also arise from different-sized mouthparts of the various animals (Chen *et al*., 1995), or on the nutrient status of the media on which the fungi were grown (Leonard, 1984). Moreover, not all Collembola fit well into the ecological box of fungivory. For instance, some springtails of the family Onychiuridae feed on roots when other food sources are absent, while those of the family Neanuridae are predaceous. In this regard Hopkin (1997) observed *Galumna* sp., an oribatid mite, feeding on nematodes in the laboratory.

Although laboratory studies are by far the easiest way to obtain information about microarthropod feeding, it is important to remember that feeding patterns observed in the laboratory do not necessarily correspond to feeding patterns in the field (Mitchell & Parkinson, 1976). The arthropod counts may not be an accurate indication of feeding activity for two reasons *viz*. (i) mouthparts are difficult to see through the microscope, so the presence of an arthropod on a given fungus might not indicate an actual feeding episode and, (ii) the observations may be too infrequent to correlate well with the amount of biomass ingested.

Another point to content with is the issue of grazing. It may directly influence fungal growth, but whether the influence is positive or negative depends on many factors, including the intensity of grazing, the nutritional

status of the fungi and the identity of the grazers (Bengtsson & Rundgren, 1988). Mineral nutrient losses have been shown to be greater in systems with oribatid mites, than without them (Seastedt & Crossley 1981; Siepel & Maaskamp, 1994). Oribatid mites with different digestive abilities can influence decomposition rates differently (Siepel & Maaskamp, 1994). They found that those mites that possessed chitinase released N as a waste product and stimulated mycelium growth when N was otherwise limiting.

Microarthropod grazing stimulates microbial respiration at low levels, but heavier grazing pressure decreases C mineralization rates (Hanlon & Anderson, 1979). They also found that microarthropod grazing enhanced the bacterial community and diminished the fungal community. These interactions between microbivores, microbes and nutrient cycling are important because the mineralization rates maintained by microbivore grazing may help maintain soil fertility for plant growth in the end (Seastedt *et al.*, 1988)

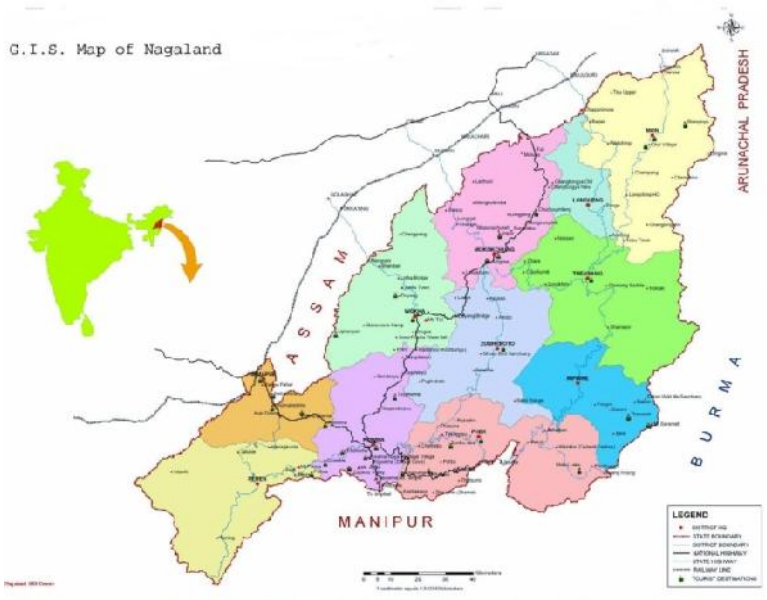
Thus, Beare *et al*. (1995) suggest that real advances will be made only when a broader view of the influence of biodiversity on soil functioning is found, explicitly including the 'complexity and specificity of biotic interactions in soils that regulate biogeochemical cycling'. A case in point is the fact that microarthropods account for only about 10% of soil respiration (Petersen & Luxton 1982), but they may influence decomposition and mineralization through both direct and indirect mechanisms (Seastedt 1984). They can contribute to decomposition directly through leaf litter comminution (break-up), and the physical breakdown creates more surface area for the microbial decomposers to attack.

Analysis of available data clearly indicated that the flow of energy and nutrients to the soil is enhanced by the activity of soil microarthropods which takes up the microflora present in the soil. Seastedt (1984) observed that microarthropods play an important role in regulating rates of decomposition and nutrient cycling via interactions with the microbial community. Iloba and Ekrakene (2008) reported that 69 % of the total decomposition was the result of soil microarthropod activity. Abundance of soil microarthropods is

indicated by the availability of nitrogen and phosphorus (Set and Burns, 1990). The soil microarthropods are also responsible for soil fertility because they release nutrients held within fungal standing crops and contribute to soil structure and humus formation as reported by Wallwork (1983) and Norton (1985).

Marshall (2000) observed that the preservation of soil biodiversity should be considered an integral component of forest management practices as the relative contributions of microarthropods to decomposition and nutrient cycling have not been specifically quantified, reductions in microarthropods abundance may be detrimental to soil processes.

In the present investigation, in both the ecosystems, there was a positive significant relationship between the chemical factors and the soil microarthropods, but the relationship with respect to potassium and phosphorus was insignificant. The chemical factors were found to be maximum in the month of June and July in forest ecosystem while in jhumland ecosystem, maximum was found in the month of May to July.



Photoplate 1: Map of Nagaland, India.

Forest ecosystem

Jhumland ecosystem

Photoplate 2: Map of Mokokchung and the study sites.

Photoplate 3: Satellite image of Mokokchung.

Photoplate 4: Forest ecosystem. (distance view)

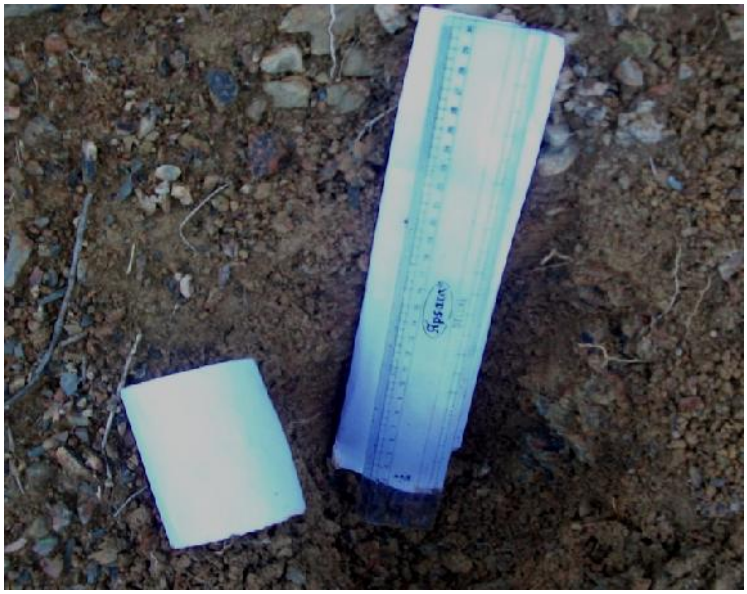
Photoplate 5: Forest ecosystem. (Closer view)

Photoplate 6: Jhumland ecosystem. (Slash and burn)

Photoplate 7: Jhumland ecosystem (after slash and burn)

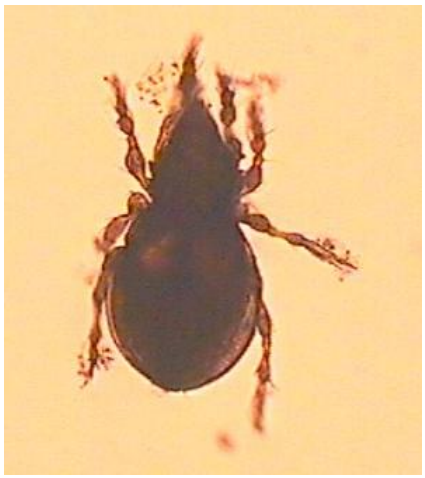
Photoplate 8: Jhumland ecosystem.

Photoplate 9: Forest ecosystem. (Sample plot)



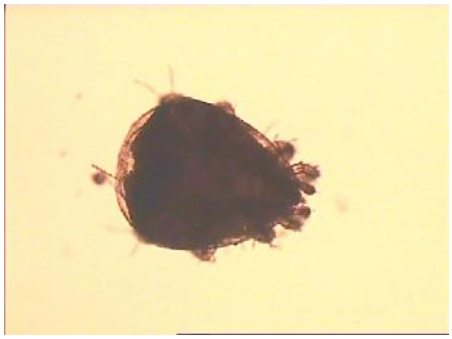
Photoplate 10: Jhumland ecosystem. (Sample plot)

Photoplate 11: Showing depth of different layers.

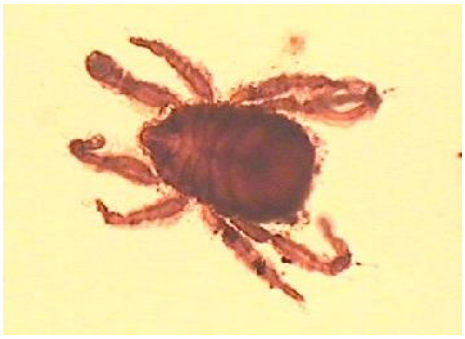


Photoplate 12: *Allosuctobelba sp.*

Photoplate 13: *Bdella longicornis*

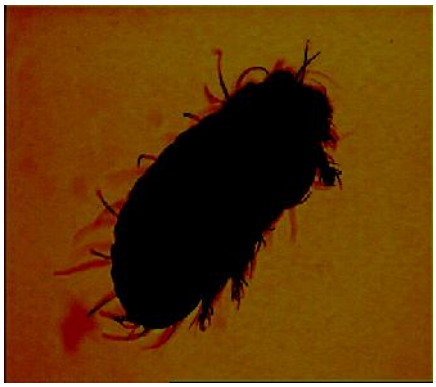


Photoplate 14: *Cosmozercon sp.*



Photoplate 15: *Dendrohermannia monstrouse*

Photoplate 16: *Gamasellus sp.*



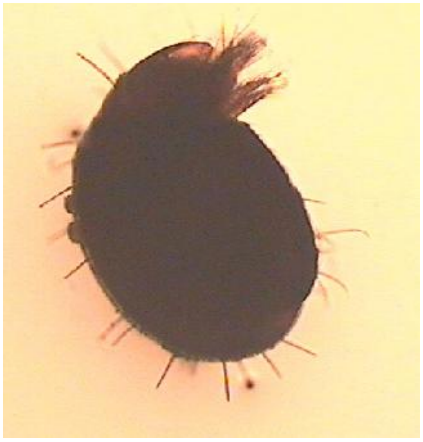
Photoplate 17: *Hermannia sp.*

Photoplate 18: *Haplozetes sp.*

Photoplate 19: *Limnozetes palinerae*

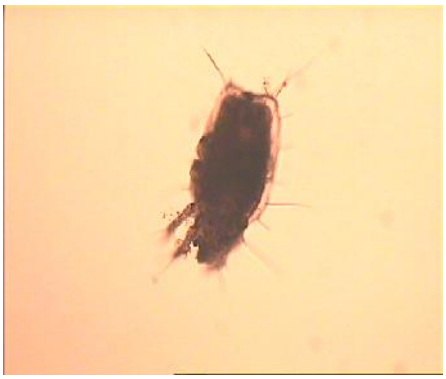
Photoplate 20: *Nothrus palustrus*

Photoplate 21: *Ololaelaps sp*

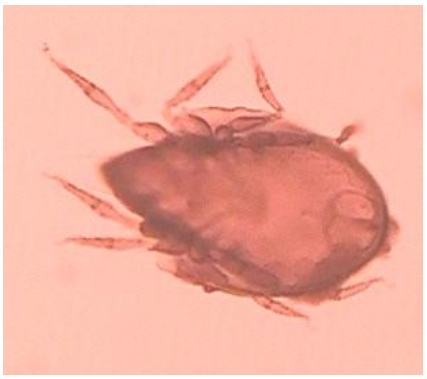


Photoplate 22: *Oribotritia sp.*

Photoplate 23: *Pergalumna sp.*



Photoplate 24: *Robustocheles sp*



Photoplate 25: *Tectocepheus sp*

Photoplate 26: *Uropoda cassidea*

Photoplate 27: *Poecilochirus* sp.

Photoplate 28: *Isotomodes productus*

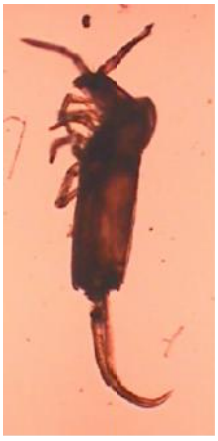
Photoplate 29: *Entomobrya triangularis*

Photoplate 30: *Entomobrya clitellaria*

Photoplate 31: *Cyphoderus albinos*

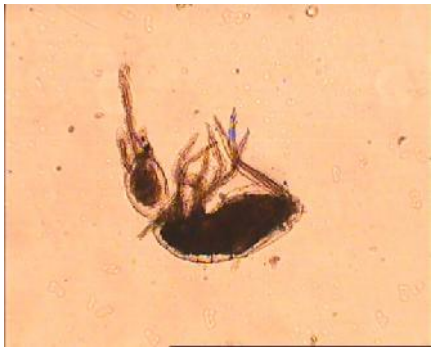
Photoplate 32: *Isotomurus unifasciatus*

Photoplate 33: *Lepidocyrtus kauriensis*



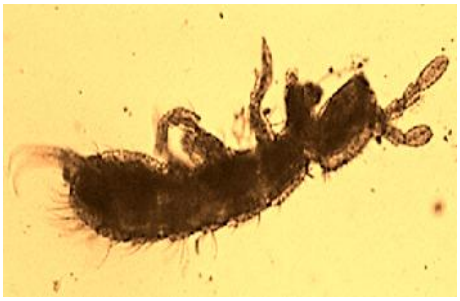
Photoplate 34: *Lepidocyrtus curvicollis*

Photoplate 35: *Proisotoma subminuta*



Photoplate 36: *Pseudosinella orba*

Photoplate 37: *Pachytullbergia scabra*



Photoplate 38: *Scutisotoma millimetrica*

Photoplate 39: *Weberacantha* magnocrella

Photoplate 40: *Dicyrtoma minuta*

Photoplate 41: *Isotomeilla minor*

The present study was carried out in two adjacent areas of forest and jhumland ecosystems in Mopongchuket village and Chuchuyimpang village under Mokokchung district, Nagaland which lies at 26°11'36'' North latitude and in between 94°17'44'' to 94°45'42'' (E) longitude. The forest site comprised of rich vegetation which had not been disturbed for more than twenty years while the jhumland had almost no vegetation due to frequent human activities and interference.

Soil microarthropods (principally mites and collembolans) are among the unseen faunal diversity in nearly all agricultural soils. They participate in the complex food webs of soils, but their importance is seldom appreciated. Laboratory and field results show that microarthropods have impacts on organic debris, microbial decomposers, nematodes, roots and pathogenic fungi. However, their impact on primary production is only indirect. Soil microarthropods are attributed with regulating many soil processes, including decomposition, mineralization, influencing populations of other soil organisms, energy flow, and nutrient cycling in ecosystems (Petersen and Luxton 1982; Seastedt 1984; Wallwork 1983; Wardle and Giller 1996). Disturbance of soil microarthropod communities has the potential to alter or disrupt these processes. But, opportunities for managing soil microarthropods in agricultural soils have been ignored.

In both the study sites, total soil microarthropods population was seen to be more in the rainy season. In the dry winter season microarthropods were still found to be thriving, and this can be attributed to post monsoon effect. In the summer physical factors such as air and soil temperature were found to be higher than the other seasons which may in turn increase the soil evaporation and less leaching of organic matter to the soil.

Different factors both physical and edaphic, at deeper soil layer may be unsuitable which may result for the lesser concentration of soil microarthropods. But the abundance of microarthropods in the upper layer may be due to constant deposit of decaying materials. This may be one of the

contributing factors for the abundance of young and immature stages as well as adults in this soil layer.

Lavelle *et al.* (1993) speculated that in the humid tropics, biological systems of regulation, *i.e*., the mutualistic interactions of fauna and microbes, are the paramount determinants of decomposition dynamics for any one leaf type. Here. It is relevant to note that the determining factors of litter decomposition rates *viz.* climate, edaphic structure, resource quality, fauna, and microbes, come into play in all terrestrial systems, though their relative importance may vary along a latitudinal gradient. Although, in temperate regions, modifications of microarthropod assemblages can influence the availability of N (Seastedt and Crossley, 1983; Heneghan and Bolger 1996), differences in assemblage structure have not been shown to influence mass loss of decomposing litter (Andren *et al.* 1995; Hoover and Crossley, 1995). This can be interpreted on the basis of climatic variability, which is greatly reduced in the humid tropics that it represents a constant, and no longer acts as a constraint on biotic activity. This is in marked contrast to temperate forests, where seasonal climatic patterns strongly constrain the biota.

The results of the present investigation showed close similarities and striking differences with the observations made by earlier workers. According to Wallwork (1970) these differences might be attributed to the local microclimatic factors which vary from plots to plots.

Community analysis was carried out with two major groups of soil microarthropods *i.e.* Acarina and Collembolan in the present study similar to the approach used in Canada by Behan & Pelletier (2003) as their contribution are maximum in term of species, abundance and distribution. A total of thirty (30) different species with fifteen (15) species in each group. The species diversity and similarities of the communities were analysed using the following indices of Margalefs index (Da) (1968), Shannon-Wiener index (H') (1949), Sorensen's index (Q/S) of similarity (1948), Average faunal resemblance and evenness or equitability index (Pielou, 1969).

In community analysis of Acarina, higher diversity indices in both the study sites have been recorded higher during rainy and summer seasons in the entire soil layer. The result show that the two study sites vary in its community and distinction. Overall the number of individuals, species and the value of diversity were found to be higher and more consistent in the forest than that of jhumland ecosystem. Among the soil microarthropods, Acarina and Collembola were the most dominant group. It was also seen that some of the species of Acarina and Collembola that were found in forest were totally absent in jhumland. It is concluded that the changes in number of taxa and density are directly correlated with temperature and rainfall, which is in consonance with the findings of Santos and Whitford (1983). Moreover, natural disturbances and anthropogenic alteration of the landscape affect soil microarthropod communities. Fire drastically reduces the numbers of microarthropods (Huhta *et al*., 1967).

Distributions of microarthropods fluctuated seasonally, tending to reach peak density during rainy and summer months, and the lowest densities occurring during winter, but this result is markedly different from that obtained by Wallwork (1970), Fujikawa (1970) and Anderson (1988), who obtained data showing peak densities during the rainy and winter seasons. The difference in the findings with earlier works may be explained on the basis of site specificity *i*.e, difference in altitude, zone and other soil biota in a particular area. Thus the present findings, along with the reports from other workers, stresses that no single factor but a combination of factors are responsible for the distribution patterns of various soil microarthropods in both the study sites.

Soil microarthropod populations in agricultural systems are known to be less diverse and less abundant because of intensive disruption of the soil or applications of biocides (Anderson 1988; Hendrix and Parmelee 1985; Wallwork 1970). Organic farming and no-tillage agricultural systems, in comparison to conventional tillage, which retains less surface organic matter, have been shown to increase numbers of 7 microarthropods in agroecosystems (House *et al*., 1984; Usher, 1985). Fertilizers have been shown to have little or

no effect upon soil microarthropod populations in forest ecosystems (Huhta *et al*., 1967, 1969; Marshall 1974). Compaction of soil because of harvesting or trampling reduces microarthropod densities (Usher, 1985; Vtorov, 1993). Forest harvesting, like the other anthropogenic practices discussed above, directly and indirectly affects microarthropod communities. The effects of intermediate disturbances, such as the silvicultural practice of thinning, can be difficult to discern due to the resilience of organisms or stands, the histories of individual sites, or geologic, geographic and/or environmental heterogeneity that overwhelm management effects (Usher, 1985; Bailey, et al., 1998; Madson, 1997). To detect the effect of thinning upon soil microarthropod community composition, it is therefore necessary to establish strong indicators of the natural heterogeneity and variability within the systems being measured.

Jhum cultivation which is wide-spread in Nagaland use the 'slash - and - burn' technique. This is a major problem area, because the jhum cycle is becoming reduced drastically with increase in population. Effects of this, as well as harvesting disturbances have been extensively studied by various workers like Abbott *et al.* (1980), Seastedt and Crossley (1981), Marra and Edmonds (1998) *etc*. In the present study, the jhumland ecosystem showed lower soil microarthropod population density, and thus, their activity will be proportionately decreased.

Microarthropod densities are related to food availability and therefore, any alterations to these food sources will have repercussions on the microarthropod communities. This has been borne out by the work of Lindo and Visser (2003), who reported that the total Acarina and Collembola abundances are correlated positively with microbial and fine root biomass. Other good works are attributed to Norton (1990), who reported that Acarina are considered k-selected organisms with low fecundity, slow metabolism, and slow generation turnover rates and thus are expected to show impacts of disturbance for longer periods. Similarly, Marshall (2000) observed that Collembolans are considered r- selected organisms with high fecundity, rapid development, and fast generation turnover rates, which allow Collembola populations to recover quickly from disturbance.

Because the responses of microarthropods to environmental factors are often non-linear and can fluctuate across seasons, it is difficult to extrapolate the net effect of fluctuating environmental controls on microarthropods. Thus, insight to their impacts on soils requires a detailed assessment of temporal patterns of microarthropod responses to changing environmental conditions.

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