DECOMPOSER ARTHROPODS IN SOIL
INTRODUCTION

As one of the important components of ecosystems soil, had recently been reviewed by Witkamp (1971). Soil, the principal substrate in which vegetation takes root, includes the dead organic material found both in and upon the mineral substrate (Drift, 1951), and the decomposing organic matter which lie immediately above it (Kevan, 1965). Soil fauna exists both in and below the litter layer often moving from one to the other. It is a broad term applicable to all the groups of animals which spend their whole life or one or more of their developmental stages, in soil or litter (Drift, 1951). Arthropods are one of the groups of soil fauna which inhabit the soil and the overlying layer of organic debris. According to Kuhnelt (1963), there was hardly an arthropodan group which was not found in the soil. The arthropods usually referred to collectively as the soil microarthropod fauna (Drift, 1951), included Acarina, Collembola, Protura, Pauropoda, Diplura and Symphyla. The first two groups are the abundant in most soils (Kevan, 1965).

The observation on soil fauna dates back to the last quarter of the 18th century (Kevan, 1965) and perhaps it may be said to have begun when White (1789) expressed his opinions concerning earthworms and mole crickets. Among the early landmarks of soil zoology were the observations of Darwin (1840, 1881) on earthworms and of Scandinavian authors, culminating in the works of Muller (1879, 1884), who considered the role of various invertebrates in humus formation. Several
studies on earthworms and a few on other groups, were published during the last part of the 19th and early 20th century. The general studies of soil fauna may perhaps be said to have begun with Diem's (1903) pioneering investigations on certain Swiss alpine soils. During the first half of the present century, possibly the most far reaching general studies on soil fauna were those of Bornebusch (1930) and Forsslund (1945), although it might appear invidious not to refer numerous other publications such as Ramann (1911), Cameron (1913), Tullgren (1917), Pillai (1922), Pfetten (1925), Escherich, 1923; Grimmett, 1926; Soudak, 1928; Tragardh, 1929. Snell (1933) had attempted to describe the general characteristics of soil microarthropod populations. The arthropod populations under different soil conditions have also been studied by many other workers including Frenzel (1936); Strenzke (1949a,b); Thompson (1924); Edwards (1929); Ford (1937); Wies-Fogh (1948); Kubiena (1955); Sheals (1957); Kuhnelt (1950, 1955, 1957, 1961, 1963); Kavans (1955, 1960, 1961, 1962); Dhillon and Gibson (1962) and Madge (1965) in different countries.

Kuhnelt (1950) summarized in a single volume, Bodenbiologie, the greater part of what was known about soil animals till that time. Franz (1950) published his Bodenzoologie where he emphasized the practical implications of the study of the soil fauna. Delamare-Deboutteville (1951) studied the influence of animals in tropical soils. Hartman (1952) based his classification of forest soils on the activities of animals and Drift (1951) published a large research work in the tradition of Bornebusch. Bellinger (1954) studied soil fauna with special reference to Collembola of four habitats of

McColl (1974) analysed the arthropod fauna of the floors of six forest types. Soil inhabiting microarthropods usually were most abundant near the surface in a zone ca 10 cm deep characterised by adequate living space, favourable moisture conditions and aeration rates and rich accumulation of organic debris (Wies-Fogh, 1948; Murphy, 1953; Harlov, 1960; Wallwork, 1970). Price and Benham (1977) stated that most arthropod groups declined rapidly in abundance with increasing depth. Wallwork (1967) felt that soil acari were primarily hemiedaphic, although their distribution may also extend into the other two zones, as with active and tolerant species. Murphy (1955) reported that the fauna of heath or forest moor was largely concentrated in the surface organic layers.
Price (1975) stated that high surface concentrations of the soil fauna to be particularly characteristic of temperate coniferous forest with more humus formation. In such habitats the fauna was largely confined to a discrete organic layer of litter and humus which overlay the mineral sub-soil (Bornebusch, 1930; Bellinger, 1954; Murphy, 1953, 1955; Wallwork, 1959; Poole, 1961; Evans et al, 1961; Fujikawa, 1970). The species composition and abundance of soil fauna are influenced by the geographical location, climate, physical and chemical properties of the soil, type of vegetative cover, nature and depth of litter and humus and a variety of other environmental factors. Thus, the soil fauna may vary considerably from one locality to another (Price, 1973). Further, he mentioned that seasonal changes in soil moisture and temperature, food supplies, biotic pressures from other components of the fauna and microflora and inherent factors in the life cycle of each species result in cyclic fluctuations and spatial movements within the soil community. Summers and Lussenhop (1976) reported that the response of soil arthropods to single habitat factors such as soil organic matter or particle size has been infrequently demonstrated. Most soil arthropod faunal studies were samples of species present in different habitats. In such studies, species differences among soil arthropods, from habitat to habitat were due to interaction of microclimate, vegetation and soil properties. Davis (1963) correlated changes in soil arthropod fauna with changes in vegetation and soil properties occurring during grassland reclamation.

Among the earlier collembolan workers, the work of
Bellinger (1954) and Christiansen (1964) were most important, where the former studied the microarthropod populations with reference to Collembola, from six different pine forest stands and the latter reviewed the early work on bionomics of Collembola. Stebaeva (1967) demonstrated the effect of climate on Collembola distribution, with reciprocal exchange of soil blocks between plant communities. Joosse (1969) investigated the population structure of six species of surface dwelling Collembola in a pine forest. Niijima (1971, 1975) studied the seasonal changes in Collembola populations in a warm temperate forest of Japan. Kaczmarek (1973) reported on Collembola in the biotopes of the Kampinos national park.

It is clear that the regular seasonal occurrence of Collembola was rare and these were readily marked by environmental conditions (Gisin, 1955). The result was that the pattern of population fluctuation varied not only from species to species but from year to year (Milne, 1962) and geographically (Christiansen, 1964). Seasonal changes of Collembola population have been studied by many investigators (Poole, 1961; Milne, 1962; Ogino et al, 1957; Marcuzzi, 1966; Choudhuri and Roy, 1967; Healey, 1967). Studies where seasonal population peaks occurred, they generally appeared in spring, in central Europe and parts of the United States, while in summer and winter in England and other regions of North America (Baweja, 1939; Sheal, 1957; Dunger, 1958). Winter populations appeared to be essentially similar in nature to summer populations, but most studies showed the occurrence or dominance of some species during the spring and summer months.

Mites constituted one of the most successful ubiquitous soil microarthropod groups (Kevan, 1965). Most mites are either free living, in soil and or litter inhabiting species (Evans et al, 1961). In litter and humus some of the most abundant species of mites belonged to the cryptostigmata (Kevan, 1965). Most of the qualitative and quantitative information on the ecology of soil acarina population relate to the European fauna, particularly of Scandinavia, much of it concerning temperate forest and grassland communities (Wallwork, 1967).

A basic understanding of the population biology of orbatid
mites was needed to assess their role in the soil, since their population parameters would directly influence their interactions with both the abiotic and biotic components of the system (Mitchell, 1977). Usher (1971, 1975) studied the seasonal and vertical distribution of a population of mesostigmatid mites in a Scots pine forest. Pandey and Berthet (1975) studied the vertical distribution of oribatid mites in a black pine woodland soil. Soil mites were important contributors to fundamental fertility, humification process and that agronomic or plant protection practices affected them adversely (Butcher et al., 1971). Attempts to correlate soil fauna with soil fertility dates back to Soudek (1928). Bornebusch (1930); Edwards and Heath (1963); Burges (1967); and Fujikawa (1970) have stressed on the role of soil microarthropods in litter decomposition and release of nutrients therefrom, which in turn had an impact on soil formation and fertility. The significance of Collembola and mites in breakdown of organic matter and soil formation had also been pointed out by Dunger (1956, 1958); Stockli (1957); Schuster (1958); Poole (1961) and Fujikawa (1970). The role played by oribatid mites in the comminution of decaying leaf tissues was of a high order. Moreover, the immature stages of oribatid mites were of greater importance in so far as decomposition of organic matter was concerned, and hence had a major role in promoting soil fertility. However, according to Hale (1967) "Insect Mull" soil as named by Muller (1879, 1884) was almost entirely formed by Collembola faeces. Microarthropods may be of considerable importance in controlling soil microflora and pests inhabiting soil by
feeding upon them. Several workers have suggested that soil microarthropods may serve as excellent indicators of soil quality, (Balogh, 1963; Ghilarov, 1965; Karg, 1968).

In contrast, information regarding the arthropod fauna of tropical soil are scanty (Raw, 1967). Most of the papers dealt with description of new taxa and other taxonomic aspects. The investigation of soil microarthropods in India, their fluctuations and effect of various factors on them, was first undertaken by Trehan (1945) in Lyallpur, now in West Pakistan, followed by Choudhury and Roy (1967, 1970) in uncultivated soils; Baduri and Raychoudhuri (1968) and Prabhoo (1976) in uncultivated and cultivated soils and by Mukherjee and Singh, 1967 and 1970); Singh and Mukherjee (1971, 1973); Singh and Pillai (1975a) and Gupta and Mukherjee (1976a,b and 1978) mostly in cultivated soils. Hence, it was clearly indicative that very few soil faunal studies exist for the tropics in general. Moreover, Indian studies was mostly if not all restricted to cultivated or uncultivated soils only. This study was therefore primarily undertaken to establish the soil faunal structure in forest soils (Singh and Singh, 1975). As the area under study comprised of pine forests our study was restricted only to the pine forest floors (Reddy and Alfred, 1977).
MATERIALS AND METHODS

Study Site, Sampling and Extraction

Samples of soil have been regularly collected for a period of 20 months from a plantation seeded in 1965. The age of the plantation was 11 years when the work commenced (Plate 4a). Samples were collected monthly and the time confined to 0900 and 1000 hrs. 10 sample units were taken at random, on each sampling occasion (Plate 4b). A rectangular iron sampler of 5x5x10 cm was used for removing the samples. A total of 200 sample units were collected and examined during the entire period of study. All the samples collected were immediately transferred to polythene bags and labelled, taking as much as possible to prevent loss of moisture. The labelled samples were brought to the laboratory for extraction within 24 hours of their collection. Berlese-Tullgren funnel series were used for the extraction (Macfadyen, 1955).

Physicochemical factors

Soil samples were collected separately for the study of physicochemical factors.

Soil temperature was measured by an ordinary mercury thermometer at 5 cm depth and at soil surface and the temperature of air, one metre above ground level.

Moisture content was measured by the dry weight method. pH and conductivity were measured by a pH metre (Toshniwal Cat. No. CL-43) and a Elico Conductivity Bridge (Elico Type CM-82). Organic carbon was analysed by the method given by Walkley and Black (1934). P_2O_5, K_2O, Fe_2O_3, CaO, MgO and Na_2O were analysed after Piper (1950).
Plate 4a  showing the 1965 plantation of 12 year old trees where soil sampling and litter decomposition studies were done.

b  showing soil profile, of the above with the litter and humus layers.
RESULTS

The term "microarthropods" as used in the present investigation designated all arthropods extracted from soil (Price, 1973). These ranged in size from less than 0.4 mm for most prostigmatids, including the juveniles of Acarina to 7 mm as in Diplopoda and Chilopoda. The extracted soil fauna were counted and sorted only up to family in Collembola and higher taxonomic levels for the others.

The abundant groups of soil fauna encountered in the present study were Acarina and Collembola (Fig. 16) followed by less commonly occurring groups like Protura, Diplura, Chilopoda, Diplopoda, Symphyla, Isopoda, Thysanoptera, Hemiptera, Araneidae, Pauropoda, Formicidae, Microcoleoptera adults and larvae, Calanoids and Diptera larvae. Five families of Collembola recorded were Isotomidae, Entomobryidae, Onychiuridae, Sminthuridae and Hypogastruridae. The group Acarina composed of Prostigmata, Hesostigmata and Cryptostigmata sub-orders. Members of the sub-order Astigmata were not encountered during the entire study period.

The quantitative composition of different groups of microarthropods for the period of investigation is presented in Fig. 16. The present investigation was carried out for a total period of 20 months beginning September, 1976. The first annual cycle was complete while the second consisted of only 8 months. Since both annual cycles could not be compared as such, the first eight months of the previous annual cycle was compared to the eight months of the second annual cycle.
Figure 16 showing the qualitative and quantitative composition of the various microarthropod groups found in the soil during the entire study period.

TC = Total Collembola  
Is = Isotomidae  
En = Entomobryidae  
On = Onychiuridae  
Hy = Hypogastruridae  
TA = Total Acarina  
Pr = Prostigmata  
Cr = Cryptostigmata  
Me = Mesostigmata  
Ar = Araneidae  
Pr. = Protura  
Dip = Diplura

TM = Total Myriapoda  
Ch = Chilopoda  
Sy = Symphyla  
Pa = Pauropoda  
Di = Diplopoda  
Iso = Isopoda  
Th = Thysanoptera  
He = Hemiptera  
CA = Coleoptera Adults  
DL = Diptera Larvae  
Hy = Hymenoptera  
C = Calanoids
Different groups of Microarthropods
When so done it was seen that the abundance of microarthropods was much more during the latter than in the former. Collembola and Acarina constituted 89.54% of the total soil arthropod population for the entire study period. Among these two, Collembola, was the most dominant group constituting 58.42%. Among Collembola, Isotomidae was the most dominant group and were recorded 49.18% of the total microarthropod population followed by Entomobryidae (4.13%), Sminthuridae (2.53%), Onychiuridae (1.89%) and Hypogastruridae (0.32%). Among Acarina, Prostigmata was the most dominant group comprising of 16.54% of the total microarthropod fauna, followed by Cryptostigmata constituting 11.11% and Mesostigmata 3.44%. Apterygota which constitute Collembola, Protura and Diplura formed 59.9% of the total microarthropod population. The group Myriapoda represented by Diplopoda, Chilopoda, Symphyla and Pauropoda constituted 1.6% of the total microarthropod population. The other groups such as Hymenoptera (Formicidae), Isopoda, Coleoptera adults and larvae, Thysanoptera, Hemiptera, Calonoids, Araneida, Diptera larvae constituted 1.23%, 0.63%, 0.48% and 0.06%, 0.42%, 0.42%, 0.27%, 0.12% and 0.06% of the total arthropod population respectively.

Seasonal Fluctuation

Fig. 17 represents the seasonal abundance of the total soil microarthropods during the period of investigation. The total microarthropod population ranged from 208x10^2 to 1600x10^2/m^2, maximum during the month of July and minimum in the month of September for the first year of study (September, 1976 to August, 1977). The month of April, 1977 had a peak representing 1356x10^2/m^2. But during the second cycle
Figure 17 showing the seasonal fluctuation of total microarthropods found in the soil during the entire study period.
The bar chart shows the number of occurrences per month from 1976 to 1978. The x-axis represents the months of the year, and the y-axis represents the number of occurrences per month, denoted as \( \times 10^2 \) per m\(^2\). The chart indicates a significant increase in occurrences during the summer months of 1977.
(September, 1977 to April, 1978) the minimum number of 240x $10^2/m^2$ was in the month of April, 1978 and the maximum occurred in the month of November, 1977 representing 836x$10^2/m^2$.

The seasonal abundance of the total Collembola group (Fig. 18) represented by all the five families (Fig. 19) reached the peak of abundance in the month of July, 1977 (1312x $10^2/m^2$) and minimum in the month of September, 1977. Besides that it had another smaller peak during the months of April and May, 1977. During the second year of investigation, the Collembola population was maximum in the month of October, 1977 and minimum in the month of April, 1978. The family Isotomidae was the most predominant group. The seasonal abundance of this family presented in Fig. 19 revealed that the number was minimum in the month of September, 1976 and the abundance fluctuated up to the month of March, 1977 and suddenly increased in the month of April, 1977 reaching a small peak of 1052x$10^2/m^2$ and then with a slight decrease in the month of May-June, 1977 reached the largest peak in the month of July, 1977 representing 1260x$10^2/m^2$. Then it suddenly decreased to 208x$10^2/m^2$. During the second year of investigation, the population fluctuation did not follow the previous year. The minimum number was recorded in the month of April, 1978 and September, 1977 representing 56x$10^2$ and 80x$10^2/m^2$ respectively, and maximum in the month of October representing 372x$10^2/m^2$.

Therefore, relative peaks of Isotomidae reflected the relative abundance of the total Collembola group and also the relative abundance of the total microarthropods.

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The family Entomobryidae was the next dominant group among Collembola. The family did not show any significant seasonal variation (Fig. 19). The maximum number was recorded in the month of November, 1976 representing $56 \times 10^2/m^2$ followed by August, 1977 representing $40 \times 10^2/m^2$ and was recorded minimum during the month of January and March, 1977. During next year of investigation the maximum number recorded was in the month of November, 1977 representing $80 \times 10^2/m^2$ individuals and minimum in the month of April, 1978.

The family Sminthuridae was next to Entomobryidae in order of abundance. The monthly catches of this family also did not show any significant variation (Fig. 19). The peaks recorded was in the month of May and August, 1977 representing $60 \times 10^2/m^2$ and $56 \times 10^2/m^2$ respectively. The minimum number was recorded during the months of September, 1976 and January, 1977. During the second cycle, the maximum numbers recorded were in the month of August, 1977 and minimum in the months of February, March and April, 1978.

The families Onychiuridae and Hypogastruridae were too few to detect changes in seasonal abundance. The peak numbers $32 \times 10^2$ to $40 \times 10^2/m^2$ in case of Onychiuridae was recorded during the month of March, 1977 and in November, 1977 respectively.

The group Acarina was the second major group of soil microarthropods (Fig. 16). The group was represented by three sub-orders. The seasonal abundance of total Acarina presented in the Fig. 18, revealed that the abundance ranged from
Figure 18 showing the seasonal fluctuation of total Collembola and Acarina found in the soil during the entire study period.

Figure 19 showing the seasonal fluctuation of Isotomidae, Entomobryidae, Onychiuridae and Hypogastruridae found in the soil during the entire study period.
84x10^2/m^2 to 416x10^2/m^2, the minimum in the month of October, 1976 followed by a sudden increase in the month of November, 1976 reaching the maximum. A second peak of abundance, 308x10^2/m^2 was recorded in the month of February, 1977. During the second year of investigation, the minimum number of Acarina recorded was in the month of September, 1977, 112x10^2/m^2 reaching a small peak of 308x10^2/m^2 in the month of November, 1977. In the month of March, the population of Acarina reached the maximum representing 40x10^2/m^2.

Among the Acarina group, Prostigmata was the most dominant group (Fig. 21). The Prostigmata population reached the maximum in the month of November, 1976 representing 264x10^2/m^2 and minimum in the month of August, 1977, 40x10^2/m^2 (Fig. 21). A small peak representing 160x10^2/m^2 was recorded in the month of April, 1977. During the second year, the minimum number recorded was in the month of September, 1977 and maximum in the month of November, 1977 and March, 1978. The relative peaks of Prostigmata abundance therefore reflected the relative peaks of abundance for the total Acarina.

Cryptostigmata was next to Prostigmata in order of abundance among the Acarina group. The Cryptostigmatid mites recorded were minimum in the month of October, 1976 representing 20x10^2/m^2 and suddenly increased in the month of November, 1976 (Fig. 21) and gradually reached the peak in the month of February, 1977. Then it gradually started decreasing with a small peak in the month of August, 1977. During the second year the number gradually increased from the month of August, 1977 and reached a small peak in the month of
Figure 20 showing the seasonal fluctuation of Protura and Diplura found in the soil during the entire study period.

Figure 21 showing the seasonal fluctuation of Prostigmata, Mesostigmata and Cryptostigmata found in the soil during the entire study period.
November, 1977 representing $80 \times 10^2/m^2$. It then suddenly decreased to a minimum in the month of December, 1977 representing $24 \times 10^2/m^2$. From January, 1978 onwards it gradually started increasing and reached the peak in the month of March, 1978 representing $152 \times 10^2/m^2$, after which it decreased.

The Mesostigmata mites of the Acarina group were too few to reflect any significant change in their seasonal abundance.

Collembola along with Protura and Diplura constituted the Apterygota group. During the present investigation Collembola were the most prominent group of Apterygota (Fig. 18). They constituted 97.53% of the total Apterygota. The next dominant group was Protura. The seasonal abundance of Protura during the first year more or less followed that of the second year. The Proturans were recorded maximum in the month of November, 1976 representing $20 \times 10^2/m^2$ and were recorded nil during the period from February to June, 1977. During the second year, the number reached maximum in the month of November, 1977 representing $36 \times 10^2/m^2$ and were minimum during the month of August, September and October, 1977 and April, 1978 (Fig. 20).

The Diplura were represented by very negligible numbers. They were recorded maximum in the month of November, 1976 representing $12 \times 10^2/m^2$ and were nil from the month of January to August, 1977. During the second year of investigation, the maximum Diplura population was recorded in the month of November, 1977 and decreased to minimum in the month of February, 1978. But in the month of March, 1978, it again showed a peak
representing $16 \times 10^2 \text{m}^2$ and then decreased to $4 \times 10^2 \text{m}^2$ in the month of April, 1978 (Fig. 20).

The group Myriapoda during the present investigation was represented by Chilopoda, Diplopoda, Symphyla and Pauropoda. The total Myriapoda represented 1.6 percent of the total population (Fig. 16). The seasonal abundance of total Myriapoda presented in Fig. 22 revealed no significant fluctuations. These were maximum in the month of February, 1977 representing $24 \times 10^2 \text{m}^2$ and minimum during the months of September, 1976 and March, 1977. They further showed a small peak in the month of July, 1977 representing $20 \times 10^2 \text{m}^2$. During the second year they were in an increased state of abundance from November, 1977 to April, 1978 and were recorded nil in the month of April, 1978.

The group Chilopoda were represented by very few individuals to detect any change in the monthly fluctuation. The family Symphyla was represented by very negligible numbers but the maximum was distinct, and was recorded during both the years during the month of November. The group Pauropoda were also recorded in very negligible numbers. They were recorded only in June and July, 1977 and from January to March, 1978 during the entire period of investigation. The group Diplopoda was recorded only in June, 1977 for the entire study period.

The other groups Formicidae, Isopoda, Thysanoptera, Hemiptera, Coleoptera adults and larvae, diptera larvae, Araneidae and Calanoids were very poorly represented (Fig. 23), and were so few to allow detection of any change in seasonal abundance. However, these groups when collectively
Figure 22  showing the seasonal fluctuation of Pauropoda, Diplopoda, Chilopoda and Symphyla found in the soil during the entire study period.

Figure 23  showing the seasonal fluctuation of Hymenoptera, Isopoda, Araneidae, Thysanoptera, Hemiptera, Coleoptera, Diptera and Calanoids found in the soil during the entire study period.
represented as miscellaneous, they exhibited considerable variation in monthly fluctuations (Fig. 23). The miscellaneous group was maximum in the month of July, 1977 representing $64 \times 10^7/m^2$ and minimum in the month of May, 1976. During the succeeding year, this group was represented maximum in December, 1977 and minimum in April, 1978. The maximum number represented during December, 1978 was due to the colony of Hymenoptera which represented nearly 87% for that month (Fig. 23).

**Physical factors**

The seasonal variation in physical factors for the study period is represented in Fig. 24. The temperature of the air inside the forest canopy, temperature at soil surface and at 5 cm depth of the soil, during the period of study varied considerably, the range being 17.0°C to 25.5°C, 16.0°C to 25.5°C and 14.0°C to 24.0°C respectively. The maximum air temperature and temperature at soil surface was recorded during July to September, 1977 and minimum during December, 1976 and December, 1977. The temperature at 5 cm depth was recorded maximum in the month of August, 1977 and minimum in December, 1976 and 1977. All these temperatures showed a definite trend of decrease starting from September, 1976 reaching the minimum in the month of December. From January onwards a gradual increase was recorded reaching the maximum during July, August and September, 1977 (Fig. 24a).

The monthly variation in the percentage of moisture content of the soil (Fig. 24a) showed a considerable variation. It ranged from 12% to 44.67%. The maximum percentage of moisture content was recorded during October, 1976 and the minimum
Figure 24 showing the seasonal fluctuation in the various physical factors of soil during the entire study period.

a Temperature of the soil surface, temperature at 5 cm depth and moisture.

b Conductivity and pH.
during January, 1977. Besides that a few smaller peaks were seen during the months of May, August, October, 1977 and February, 1978.

The pH of the soil was acidic, ranging from 4.47 to 6.47 units. The maximum pH was recorded in the month of February, 1977 and minimum in the month of October, 1976. Besides that, the pH showed another peak of increase during the month of March, 1978. The monthly variation in pH during the present study was considerable (Fig. 24b).

The conductivity ranged from 14.88 to 41.3 μmhos/cm². The minimum conductivity was recorded in the month of May, 1977 and maximum in the month of July, 1977. A second peak of increase was recorded in the month of February, 1978 representing 37.45 μmhos/cm².

**Chemical factors**

Phosphorus (P₂O₅) ranged from 3.6 to 29.6 pound per acre, the maximum being in the month of March, 1977 and minimum in the month of February, 1978 (Fig. 25a). Pottasium (K₂O) was very abundant comparatively and ranged from 140 pounds per acre to 650 pounds per acre, the maximum being in the month of August, 1977 and minimum in the month of November, 1977. A few smaller peaks of maxima were recorded during the months of January, March and June, 1977 and March, 1978 (Fig. 25a). The percentage of organic carbon ranged from 2.25% to 4.58%, the maximum being in the month of March, 1977 and minimum in the month of January, 1978. Besides that, the percentage of organic carbon also had a peak during June, 1977 (Fig. 25b). There was very little monthly variation in percentage of
Figure 25 showing the seasonal fluctuation in the various chemical factors of soil during the entire study period.

a $P_2O_5$, $K_2O$

b Total iron, organic carbon

c $CaO$, $MgO$, $Na_2O$
total iron content. It ranged from 4.06% to 5.43%, the maximum being in the month of November, 1976 and minimum in the month of May, 1977.

The percentage of Calcium (CaO), Magnesium (MgO) and Sodium (Na_2O) was very negligibly represented and the monthly variations could not be detected. Calcium (CaO) was recorded from trace to 0.21%. The maximum amount was recorded in August, 1977, and the trace was recorded during December, 1976, March and April, 1977, May and June, 1977, October, 1977 and April, 1978. Magnesium (MgO) content ranged from trace to 0.45%. The maximum amount was recorded in November, 1977. The content of Sodium (Na_2O) ranged from 0.12% to 0.17%, the maximum being recorded in the month of October, 1976 and minimum in the months of January, April and December, 1977 and January and April, 1978.
DISCUSSION

Drift (1951) reported $3365 \times 10^2/m^2$ of arthropods in a beach forest soil, while Harding (1969) and Price (1973) found $2150 \times 10^2/m^2$ in an oak woodland and more than $2207 \times 10^2/m^2$ in pine forest soil respectively. In the present study where a maximum of $1600 \times 10^2/m^2$ have been reported was much lower than these and the nearest comparison could only be made with the temperate pine forest soil where Crossley and Bohnsack (1960) reported $1020 \times 10^2/m^2$. Drift (1963) and Greenslade and Greenslade (1968) reported $514 \times 10^2/m^2$ and $920 \times 10^2/m^2$ respectively from tropics and compared their estimates with those of earlier tropical workers and reported that there was no significant difference. The present study site located at an altitude of Ca 1175 m approached to near temperate climatic regimes, but still the total microarthropod densities reported fell between those of reported temperate and tropical estimates.

The seasonal fluctuation in the total microarthropod population did not show any regularity in their peaks of abundance for entire period of study. A comparison made between the first eight months of both the years studied showed a maximum of $1356 \times 10^2/m^2$ during April, 1977 while it was minimum for the same month during 1978. Since the study was not extended to complete the second annual cycle no concrete conclusion in the total microarthropod population and their pattern of trend could be drawn. In any case, however, the trend during the first eight months of both the annual cycles being not similar, the effect of season seemed to be minimal on the relative
abundance of total microarthropods. This was confirmed by a perusal of Table-VIIa, where none of the abiotic factors except rainfall had any significant correlation with the total microarthropods. However, it was known that edaphic and climatic factors influenced the development and maintenance of any soil community (Drift, 1963). This was supported by Usher (1971) who reported that populations of soil arthropods were affected by the two factors of temperature and precipitation. The physical factors like pH and conductivity and all the chemical factors under study seemed to have no significant effect on total microarthropods when they were either positively related or negatively related.

Of the total microarthropods, Collembola and Acarina constituted a major portion comprising of nearly 89.54%. Among these two, Collembola dominated Acarina and was 58.42% during the total study period and ranged between $24 \times 10^2$ and $1312 \times 10^2$ / m$^2$. Such an abundance of Collembola has also been reported earlier by other workers like Tragardh (1929) - $1200 \times 10^2$/m$^2$; Kaczmarek (1973) - $170 \times 10^2$ to $220 \times 10^2$/m$^2$; Price (1973) - $1461 \times 10^2$/m$^2$ and Tamura (1976) exceeds the order 105 individuals/m$^2$.

The trend in seasonal fluctuation of total Collembola showed one large and two small peaks of abundance during an annual cycle. The two smaller peaks occurred during the post-monsoon months of October and November and the post-winter month of February. The larger peak occurred during April - July which is the monsoon season for the present study undertaken. A comparison of these peaks of abundance could be done.
Table VIIa  Coefficient correlation between the monthly abundance of total microarthropods, total Collembola, total Acarina, Myriapoda, insects other than Collembola and Acarina and various physico-chemical factors.
<table>
<thead>
<tr>
<th>Physical Factors</th>
<th>Total Micro-Arthropods</th>
<th>Total Collembola</th>
<th>Total Acarina</th>
<th>Total Myriapoda</th>
<th>Arthropods other than Collembola and Acarina</th>
<th>Apterygota</th>
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<td>Air Temp.</td>
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<td>0.4363 &lt;sup&gt;*&lt;/sup&gt;</td>
<td>-0.5212&lt;sup&gt;*&lt;/sup&gt;</td>
<td>-0.1852&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>-0.3903&lt;sup&gt;NS&lt;/sup&gt;</td>
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</tr>
<tr>
<td>Temp. at Soil Surface</td>
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<td>0.3408 &lt;sup&gt;NS&lt;/sup&gt;</td>
<td>-0.4655&lt;sup&gt;*&lt;/sup&gt;</td>
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<td>0.4120 &lt;sup&gt;NS&lt;/sup&gt;</td>
<td>-0.5318&lt;sup&gt;*&lt;/sup&gt;</td>
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<td>-0.3113&lt;sup&gt;NS&lt;/sup&gt;</td>
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</tr>
<tr>
<td>Soil Moisture</td>
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<td>-0.6899&lt;sup&gt;**&lt;/sup&gt;</td>
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<td>0.3214&lt;sup&gt;NS&lt;/sup&gt;</td>
</tr>
<tr>
<td>Rainfall at previous month</td>
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<td>0.5961&lt;sup&gt;**&lt;/sup&gt;</td>
</tr>
<tr>
<td>pH</td>
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<td>0.8769 &lt;sup&gt;**&lt;/sup&gt;</td>
<td>0.2696&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>0.6300&lt;sup&gt;**&lt;/sup&gt;</td>
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<td>-0.1710&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>-0.1225&lt;sup&gt;NS&lt;/sup&gt;</td>
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<td>0.4890&lt;sup&gt;*&lt;/sup&gt;</td>
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<td>-0.2778&lt;sup&gt;NS&lt;/sup&gt;</td>
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<td>0.2842&lt;sup&gt;NS&lt;/sup&gt;</td>
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<tr>
<td>CaO</td>
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<td>-0.4307&lt;sup&gt;*&lt;/sup&gt;</td>
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<td>-0.1494&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>0.0533&lt;sup&gt;NS&lt;/sup&gt;</td>
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<td>0.1349&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>-0.2187&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>0.0373&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>0.1580&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>0.1429&lt;sup&gt;NS&lt;/sup&gt;</td>
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</tbody>
</table>

NS = Not significant  
* = P<0.05  
** = P<0.01
with other forest soils and in particular coniferous soils of
the temperate region, if our monsoon was summer season and the
post-monsoon and post-winter be attributed as autumn and spring
respectively. If so, Poole (1961) reported summer maxima with
smaller winter peaks and Bellinger (1954) recorded a spring
peak while Jooose (1969) showed maximum for some species during
spring and autumn and others during summer. A better comparison
would however be with that of tropical forest soils, where most
of the work was confined to South East Asia and Japan. In such
cases, Ogino et al (1965) reported an increase in Collembola
from August to March with an abrupt rise in May while Takeda
(1973) recorded two peaks one in December and the other in
March. Niijima (1975) reported three peaks in a year for the
dominant species of Collembola studied. Though all comparisons
made were between forest soils, yet no definite trend of fluc-
tuation in population density was seen similar in any two
studies. Such lack of definite fluctuations could be attribu-
ted to differential preferences of individual species, their
migration, natality and mortality dissimilar to one another,
having a disadvantage in the total presentation of seasonal
population fluctuation as Collembola in general (Jooose, 1969).
Different climatic conditions prevailing in different regions
could also have an effect on the pattern of fluctuation allow-
ing no true comparisons between any two regions (Niijima,
1975).

All the five families represented in Collembola have been
recorded during the current study. Of these, the family Iso-
tomidae was the most dominant in abundance while Hypogastruri-
dae was the least. A perusal of Fig. 19 revealed that the
population trend of fluctuation for the family Isotomidae followed the same pattern as that of total Collembola. This was not surprising since they formed 84.14% of the total Collembola. Other than the attributes given for total Collembola, in relation to the peaks of abundance, nothing thought provoking could be added for Isotomidae. Regarding the other families, the pattern of fluctuation was so irregular that no conclusions regarding their seasonality could be drawn. The only possible reason for rise and fall in populations successively was that the families Entomobryidae, Sminthuridae and Onychiuridae had several generations of overlapping populations.

The maximum Collembola occurring during rainy months showed a significant positive relationship \( r = +0.5950 \) and \( P < 0.01 \) with rainfall. The other abiotic factors which had a similar relationship though only at \( P < 0.05 \) level was also understandable as the population started building up during the onset of summer. These results find support of Kevan (1965); Butcher et al. (1971) and Gupta and Mukherjee (1978) where they reported a marked effect on soil arthropods by the influence of temperature. Niijima (1971) had attributed that temperature was one of the main causes for the low density of Collembola during winter. Temperature was one factor responsible for oviposition and growth rate of Collembola (Kevan, 1955, 1965 and Hale, 1966, 1967) could be the probable reason for their increase in abundance during the summer. Among the physico-chemical factors only pH and CaO were significantly related to total Collembola, the former being positive at \( P < 0.01 \) level and the latter negatively at \( P < 0.05 \) level. The
pH during the present study was always on the acidic side and therefore the Collembola species encountered were related to acidity (Hale, 1966; Nosek, 1967) and seem to have a distinct preference for that range. On the other hand there exists more reports on pH having very little or no effect on Collembola populations (Agrell, 1941; Bellinger, 1954; Paclt, 1956; Cassagnau, 1961, 1964 and Christiansen, 1964).

Among the different families of Collembola, Isotomidae the dominant group also had the same correlations significant as for total Collembola. The other two families Entomobryidae and Sminthuridae were not effected by any abiotic either physical or chemical factors except MgO which did show some relation to Entomobryidae.

The group dominant next to Collembola during the present investigation was Acarina. Though so, it represented only half of the total Collembola in relative abundance. As a group, Acarina followed a more or less similar pattern in their fluctuation to that of Collembola. Their peaks of abundance occurred during pre-winter (late autumn), post-winter (early spring) and monsoon (mid-summer). The first eight months of the two annual cycles were similar in their trend of fluctuation for Acarina except for their peaks of abundance being reversed. The maximum numbers recorded were during the months of September and October for both the annual cycles. For most temperate soils, a July peak for Acarina was a common finding (Bellinger, 1954; Madge, 1965). Peaks of abundance in November was also not unusual (Curry, 1971), except that in the present study, the range being much more in November than in July, not
reported earlier. The possibility of an over-wintering popula-
tion making its impact in summer as in temperate soils was not
as significant as the population building up after the monsoon
as seen in the present study. Altitude and the climatic regime
of the present study site should probably be one factor having
a similarity near to temperate conditions.

Among Acarina all the three sub-orders had been recorded
during the present study. The sub-order Prostigmata was the
most abundant comprising of 53.02% of the total Acarina. The
peaks of abundance in their seasonality followed more or less
a similar pattern as that for the whole order except than an
extra peak was observed in the month of April during first
annual cycle. A dominance of the sub-order Prostigmata had
been earlier reported by Loots and Ryke (1967) and Price (1973)
though reports exist of the group having very low density
(Madge, 1965 and Block, 1965, 1966). Their dominance could be
attributed to their adaptation as a group tolerant of external
environmental conditions of the region under study (Loots and
Ryke, 1967).

Cryptostigmata followed Prostigmata in order of abundance
during the present study. Though Price (1973) is in agreement,
yet Madge (1965) and Wallwork (1967) had different views to
that of the present study, for the latter two had reported
more than 75% of the sub-order Cryptostigmata in their respec-
tive works. The trend in the population fluctuation of this
sub-order did not follow any significant seasonal variation.
The only period when they were in an increased state was
during March of both the years attributed to the probability
of an overwintering population making its effect felt during early spring. The low population abundance was seen during the summer. Reports of such trends were found in Wallwork (1959); Evans et al. (1961) and Madge (1965). As species could not be identified during the present study, no conclusions could be drawn from the seasonal fluctuations of the whole group as Usher (1975) had clearly pointed out that different species had not only different peaks of abundance but also the number of peaks varied between species. This was further confirmed by Harlov (1960); Evans et al. (1961); Block (1966) and Mitchell (1977) who had reported well defined bimodal peaks for most oribatid groups.

The sub-order Mesostigmata during the present study was not only too few in number (Price, 1973 and Madge, 1965) but also showed no seasonal trend in their fluctuation (Usher, 1971). Hence no significant conclusion could be drawn from them.

Though the trend of fluctuation was more or less similar as for Collembola, the effect of the various abiotic factors had a very significant relationship on the total Acarina population. A very interesting observation revealed from the present study showed, temperature (air, soil surface and at 5 cm depth), rainfall and moisture were negatively correlated and were highly significant, at $P < 0.05$ level for the former two and at $P < 0.01$ for the latter with total Acarina. As for the other physical factors like pH and conductivity and for all the chemical factors, no significant relationship was found and hence probably had very little role to play in
regulating the Acarina population. Though some investigators did show no relationship between soil moisture and Acarina (Macfadyen, 1952, 1954; Huther, 1961; Marcuzzi, 1967, 1968, 1973) yet others reported definite negative correlation (Hammer, 1934, 1937, 1953 and Stebayev, 1962). It was known that the effect of moisture was complex, indirect and to a large extent interwoven with that of temperature (Glasgow, 1939; Gisin, 1943, 1952). Such a relationship existing between temperature and moisture was also found in the present study, as both the factors were negatively correlated. One could not go far too wrong if along with the above two factors rainfall was also included. Belfield (1964) and Gupta and Mukherji (1978) had reported excess moisture or water logged conditions to adversely affect microarthropod populations. pH not having any effect on Acarina unlike Collembola was understandable as it's correlation with the density of Acarina would be misleading when effects of temperature, humidity and animal respiration combined, acidify the substrate (Lebrun, 1965; Frank, 1965 and Loots and Ryke, 1967).

Among the various groups of Acarina it was intriguing to find that not all the abiotic factors affected their population densities, than when they are clubbed together. This was more so, especially when even the dominant group Prostigmata did not follow the total Acarina for they were significantly negatively correlated only with air temperature and soil moisture and positively correlated with total iron. Cryptostigmata was negatively correlated for the abiotic factors like moisture, pH and CaO while positively correlated for total
Table VIIb  Coefficient correlation between the monthly abundance of Isotomidae, Entomobryidae, Sminthuridae, Prostigmata, Mesostigmata, Cryptostigmata and various physico-chemical factors.
<table>
<thead>
<tr>
<th>Physical Factors</th>
<th>Entomobryidae</th>
<th>Isotomidae</th>
<th>Sminthuridae</th>
<th>Prostigmata</th>
<th>Mesostigmata</th>
<th>Cryptostigmata</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temp.</td>
<td>-0.2219&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>0.4417&lt;sup&gt;*&lt;/sup&gt;</td>
<td>0.3670&lt;sup&gt;NS&lt;/sup&gt;</td>
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<td>-0.4457&lt;sup&gt;*&lt;/sup&gt;</td>
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</tr>
<tr>
<td>Temp. at Soil surface</td>
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<td>Temp. at 5cm depth</td>
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</tr>
<tr>
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<td>-0.1230&lt;sup&gt;NS&lt;/sup&gt;</td>
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</table>

<sup>NS</sup> = Not significant  
* = P<0.05  
** = P<0.01
iron. The last group Mesostigmata was negatively correlated with air temperature, temperature at 5 cm depth and organic carbon \((P < 0.05)\) while positively correlated with pH (Table-VIIb). This was a clear indication, as mentioned earlier while dealing with total Acarina, that temperature, rainfall or moisture either singly or together with one of the other factors or all three combined together did play a significant role in controlling the different sub-orders of Acarina. As regards the organic matter with Mesostigmata, this was probably the first time that a negative correlation had been found. Most of the authors were of the opinion that highest densities of arthropods were recorded by many workers where the organic matter was more and organic substance being rich, depending on the humus of the environment (Poole, 1961; Lutz and Traitteur, 1965; Choudhuri and Roy, 1967; Loots and Ryke, 1967; Butcher et al, 1971; Niijima, 1971 and Castri, 1973).

Other than the groups discussed earlier, Protura, Diplura, Pauropoda, Symphyla, Chilopoda, Diplopoda, Isopoda, Thysanoptera, Hemiptera, Hymenoptera, Coleoptera adult and larvae and Diptera:larvae, Calanoids and Arachnida, were also present among the microarthropods during the present investigation. Except for Protura, Chilopoda and Hymenoptera which were a little more than 1% of the total microarthropods, all the others were recorded less than 1%. Moreover, all these were very few in number and not being present throughout the year no seasonal pattern in their trend of fluctuation was found. An interesting observation made during the present study was the occurrence of Formicidae (Hymenoptera) in the month of
December, 1977 in such large numbers having a predatory effect on the population of most other groups as was obvious in their low numbers being revealed during that month.

While considering the remaining groups together it was seen that none of the physical factors had any effect and among the chemical factors only organic carbon ($P<0.05$) had a significant negative correlation. It further proved that as in Mesostigmata, the organic carbon and its abundance drastically effected the population of most microarthropods.
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<td>1944</td>
<td>Studies on the Oribatid and Collembola of Greenland</td>
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