

**STUDY OF SOIL MICROFLORA IN
TWO SACRED GROVES OF MEGHALAYA**

ABSTRACT



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ABSTRACT

The present research investigation deals with bimonthly enumeration and isolation of soil fungi and bacteria, microbial biomass C, enzymes activities and soil physico-chemical characteristic. The investigation was carried out at two sacred groves (Khloo Langdoh and Khloo Paiung) and pine forest of Jaintia Hills Meghalaya situated at Jowai the head quarter of Jaintia Hills, which is 60km away from Shillong.

The geographical position of Jowai is at 25° 26' 32" N Latitude, and 29° 12' E Longitude and situated at 1300m asl. The average maximum and minimum temperature during the study period was recorded are 25°C and 13.1°C in 2002 and 26°C and 14°C in 2003 respectively. The average rainfall was 360.6mm in 2002 and 265.2mm in 2003. The month of June was recorded the higher rainfall in both the years (i.e. 1283.8mm and 1178.6mm respectively). The soil samples were collected from three soil depths, (0-10cm, 10-20cm, 20-30cm), and the soil were analyzed for a variety of physical and chemical characteristics.

The fungal populations were higher in sacred groves than in the pine forest. In the first year (2002) of study, maximum fungal population was observed in rainy season in June and October and minimum in winter season in February and December in both the sacred groves. The fungal population in most cases is generally high at the surface soil layer (0-10cm) than at the sub surface soil layer (10-20cm and 20-30cm). In the second year (2003) of

study, maximum fungal population showed in April and August in Khloo Paiung and minimum in December in both the sacred groves. In both the years (2002 and 2003) the fungal populations were lower in pine forest in comparison to the sacred groves.

The investigation also showed that there is a declined of soil fungal population with soil depths. The population is higher at the surface soil layer (0-10cm) and lowers at the sub surface soil layer (10-20cm, 20-30cm). In Khloo Paiung fungal population showed positive correlation with total nitrogen, organic carbon, urease activity, dehydrogenase, moisture content and bacterial population. In Khloo Langdoh it showed positive correlation with total nitrogen, microbial biomass carbon, moisture content and bacterial population. In pine forest it showed positive correlation with total nitrogen, organic carbon, microbial biomass carbon, dehydrogenase, phosphatase activity moisture content and bacterial population.

All together 90 fungal species and 5 sterile mycelia were isolated (75 species = Khloo Paiung, 66 species = Khloo Langdoh and 59 species= Pine forest) and out of these, *Aspergillus* sp, *Penicillium* sp, *Oidiodendron* sp and *Trichoderma* sp. were the dominant species, *Alternaria tenuissima*, *Broomella acuta*, *Papula spora*, *Penicillium rubrum*, *Zygorrhynchus heterogamous*, *Scopulariopsis brevicaulis*, were isolated from Khloo Paiung only, while *Alternaria alternata*, *Cylindrocarpon didymum*, *Oidiodendron rhodogenum*, *Preussia fumiculata*, *Penicillium herquiei* and *P. ilandicum* were isolated from Khloo Langdoh only. 54 species are common to both the sacred groves, 46

species are common to Khloo Paiung and Pine forest, while 39 species are common to Khloo Langdoh and Pine. In general, high species diversity of fungi was noted in the two sacred groves than in the pine forest. In the first year (2002), diversity of fungi were high in Khloo Paiung, while in the second year (2003), high diversity of fungi were observed in Khloo Langdoh, except in few cases it showed some increase in pine forest. Similarity index showed a similar trend in all the three forest stands.

Bacterial population increased in rainy season in all the three forest stands. In the first year (2002), maximum bacterial population was observed in August and minimum in February in Khloo Paiung. In the second year (2003), maximum bacterial population in June in all the three forest stands and minimum in December in the two sacred groves and in August in the pine forest. Between the sampling periods the bacterial population declined with soil depth, which recorded highest population at the surface soil layer (0-10cm) and minimum population was recorded at the sub surface soil layer (10-20cm, 20-30cm).

In Khloo Paiung the bacterial population showed positive correlation with moisture content, organic carbon, total nitrogen, available phosphorus, dehydrogenase phosphatase and fungal population. In Khloo Langdoh the bacterial population showed positive correlation with moisture content, organic carbon, total nitrogen, microbial biomass carbon, dehydrogenase, urease and fungal population. In pine forest the bacterial population showed positive correlation with total nitrogen, microbial biomass carbon, urease,

phosphatase and fungal population. Altogether, 8 bacterial species were isolated. *Microccus* sp, *Arthrobacter* sp and *Rhizobium* sp were the dominant species. In general diversity index of bacteria was noted in the two sacred groves. It was high at sub surface soil layer in June and October in Khloo Paiung in year first (2002). While, it was high at sub surface soil layer in February in pine forest in the second year (2003). Similarity index showed similar trend in all the three forest stands.

The soil moisture content was higher at the surface soil layer (0-10 cm) and lower at the subsurface soil layer (10-20cm & 20-30 cm). The soil pH ranged between 4.75 - 6.5 in all the depths (0-10cm, 10-20cm and 20-30cm), the soil pH showed negative correlation with all soil parameters.

Seasonal fluctuation of soil organic carbon was observed, where it was higher during warm season and lower during cold season. There is an increased percentage of organic carbon in both the sacred groves than in the pine forest. The organic carbon varied with soil depth as it tends to be more at the surface soil layer (0-10cm) than at the subsurface soil layer (10-20cm and 20-30cm). In Khloo Paiung the correlation coefficient values of soil moisture content showed a positive correlation with total nitrogen, available phosphorus, potassium, microbial biomass carbon, dehydrogenase, phosphatase, bacterial population and fungal population. In Khloo Langdoh the correlation coefficient values of soil organic carbon showed a positive correlation with total nitrogen, available phosphorus, potassium, microbial biomass carbon, dehydrogenase, and bacterial population.

Organic carbon varied significantly ($P \leq 0.001$) at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in all the three forest stands.

Total nitrogen showed increased percentage in both sacred groves than in the pine forest. Peak percentage of total nitrogen was observed in August 2002 and October 2003. While it also showed peak percentage at the surface soil layer (0-10cm) than at subsurface soil layer (10-20cm and 20-30cm). The correlation coefficient values of soil moisture content showed a positive correlation with available phosphorus, potassium, organic carbon, microbial biomass carbon, dehydrogenase, phosphatase, moisture content, bacterial population and fungal population in Khloo Paiung. In Khloo Langdoh the correlation coefficient values of soil organic carbon showed a positive correlation with organic carbon, dehydrogenase, phosphatase, moisture content, bacterial population and fungal population. In pine forest the correlation coefficient values of soil organic carbon showed a positive correlation with available phosphorus, organic carbon, microbial biomass carbon, bacterial population and fungal population. Total nitrogen varied significantly at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in all the three forest stands.

The soil phosphorus is high in both sacred groves than in pine forest. Seasonal fluctuation was observed, where it was high in June and low in December in both the year but it was higher in the first year of study. Soil phosphorus was high at the surface soil layer (0-10cm) and low at the

subsurface soil layer (10-20cm and 20-30cm). In Khloo Paiung the correlation coefficient values of available phosphorus showed a positive correlation with total nitrogen, potassium, organic carbon, phosphatase and bacterial population. In Khloo Langdoh the correlation coefficient values of available phosphorus showed a positive correlation with organic carbon, potassium and microbial biomass carbon. In pine forest the correlation coefficient values of available phosphorus showed a positive correlation with total nitrogen, organic carbon and microbial biomass carbon. Available phosphorus varied significantly with soil depth between 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in pine forest and Khloo Paiung and at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20cm x 30cm in Khloo Langdoh.

Soil potassium showed more concentration in both sacred groves than in pine forest. It showed seasonal variation where it tends to be more in winter season and low in rainy season. In Khloo Paiung the correlation coefficient values of potassium showed a positive correlation with total nitrogen, available phosphorus organic carbon, and microbial biomass carbon. In Khloo Langdoh the correlation coefficient values of potassium showed a positive correlation with available phosphorus, organic carbon, microbial biomass carbon and moisture content. In pine forest the correlation coefficient values of potassium showed a positive correlation with moisture content only. Soil potassium varied significantly with soil depth between 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm in Khloo Paiung and Khloo

Langdoh and at 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in pine forest.

The soil microbial biomass C increased in both sacred groves than in pine forest. Soil microbial biomass C declined from the surface soil layer (0-10cm) to the sub surface soil layer (10-20cm, 20-30cm). It showed seasonal variation where it is more in the spring or warm season and low in winter or cold season and rainy season in few cases. In Khloo Páung soil microbial carbon was positively correlated with total nitrogen, potassium, organic carbon and urease. In Khloo Langdoh soil microbial carbon was positively correlated with available phosphorus, potassium, organic Carbon, dehydrogenase, bacterial population and fungal population. In pine forest soil microbial carbon was positively correlated with total nitrogen, available phosphorus, organic carbon, dehydrogenase, bacterial population and fungal population. Microbial biomass C varied significantly ($P \leq 0.001$) between 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm soil depths in Khloo Páung between 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm soil depths in Khloo Langdoh and pine forest.

The activities of soil enzymes (dehydrogenase, urease and phosphatase) were quite similar in all the three forest stands, except in few cases where it is more in the two sacred groves. Enzyme activities showed seasonal variation. It is high in rainy and low in winter season. It is more at the surface soil layer (0-10cm) than in the subsurface soil layer (10-20cm and

20-30cm). Dehydrogenase activity was high in June and August and low in February in 2002. In 2003 it was high in August and low in February and December in Khloo Paiung which is similar to that of Khloo Langdoh and pine forest. In Khloo Paiung dehydrogenase activity showed positive correlation with total nitrogen, organic carbon, soil moisture bacterial population and fungal population. In Khloo Langdoh it showed positive correlation with total nitrogen, Cmic, urease, phosphatases, and bacterial population. In pine forest it showed positive correlation with organic carbon, Cmic, and fungal population. Dehydrogenase activity varied significantly ($P \leq 0.001$) between 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm soil depths in all the three forest stands.

Phosphatase activity was high in June for Khloo Paiung and October for Khloo Langdoh and pine forest in 2002. In 2003 it showed high activity in October for Khloo Paiung and Khloo Langdoh and minimum in February. Phosphatase activity varied significantly ($P \leq 0.001$) between 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm and 0-10cm x 20-30cm soil depths in Khloo Langdoh, between 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm soil depths in Khloo Paiung and between , 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm soil depths in pine forest.

Urease activity was high in June in 2002 but low in February in 2002 and 2003 respectively for all the three forest stands. Urease activity is more at the surface soil layer (0-10cm) than at the subsurface soil layer (10-20cm) and

(20-30cm). In Khloo Paiung, urease activity was positively correlated with C_{mic} , available phosphorus and fungal population. In Khloo Langdoh urease activity was positively correlated with dehydrogenase, available phosphorus and bacterial population. In pine forest, urease activity was positively correlated with bacterial population. Urease activity varied significantly ($P \leq 0.001$) between 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm soil depths in Khloo Paiung. Insignificant variation in Khloo Langdoh and pine forest in all the soil depth.

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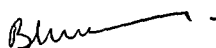
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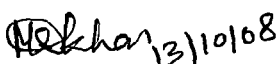
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I, **B. GASHNGA** hereby, declare that the subject matter of this thesis entitled "Study of microflora in two sacred groves of Meghalaya" is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous 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 other University/ Institute.

This is being submitted to the North Eastern Hill University, Shillong for the award of the degree of Doctor of Philosophy in Botany.



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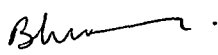
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Plate 1: Khloo Paiung



Plate 2: Khloo Langdoh

CHAPTER 1

1.1. GENERAL INTRODUCTION

An increasing interest has emerged with respect to the importance of microbial diversity in soil habitat. The extent of the diversity of microorganisms in soil is seen to be critical to the maintenance of soil health and quality, as a wide range of microorganisms is involved in important soil function. Soil microorganisms are very important as almost every chemical transformation taking place in soil involves active contributions from soil microorganisms. Soil microbial community plays a fundamental role in the ecosystem functioning, because it decomposes organic matter, determining the release of mineral nutrients in the soil and, consequently, influencing primary productivity and nutrient cycling. On the other hand, soil microorganisms may be affected by plant cover that influences chemical-physical properties of the soil.

Soil represents heterogeneous habitat in which the environmental conditions can differ markedly from one microhabitat to the next. These microhabitats in the soil correspond to a large number of ecological niches, in which microorganisms are present. The effect of soil on its microflora, soil type likely represents another important factor influencing the structure of microbial communities. Soil on the basis of different particle size distribution, pH, cation exchange capacity, or organic matter content, thus can affect microbial community structure either directly, i.e. by providing a specific

habitat that selects specific microorganisms or indirectly, i.e., by affecting plant root functioning and exudation in a soil specific manner.

In all ecosystems soil microorganisms play important roles in decomposition of organic matter, nutrient cycling and plant nutrient availability, thus they are essential components in the functioning of the whole ecosystem. The structure and functional diversity of the microbial communities in the soil is tightly related to plant species composition above – ground, thus providing an important link between above and below ground processes in terrestrial ecosystems (Grayston and Campbell, 1996; Grayston *et al.*, 2001). In order to understand the structure and function of the soil ecosystem, it is important to analyze the factors regulating the size of microbial populations and their activities.

At the time when ecological degradation and deforestation have been taking place at an alarming rate throughout the globe in Northeast India there are hundreds of natural vegetation scattered throughout the region are preserved almost in a pristine condition such pockets are commonly referred to as sacred groves. These sacred groves are completely undisturbed from human interference due to religious beliefs. In Meghalaya these are set aside for religious purposes and are managed by the religious Head or Priest. One of the facts that make sacred groves such important factors in conservation is that the behavior enjoined in regard to them protected not just the trees, but every possible element of the habitat and as such they are very rich in biodiversity. Their importance in biodiversity conservation has long been recognized (Khiewtam and Ramakrishnan, 1993; Ramakrishnan, 1998). They

offer very important information on their genetic resources on site, within the natural or original ecosystems in which they occur, their ecological status and the level of interaction between life forms (Mc. Neely, 1994; UNEP, 1995 and Edwards *et al.*, 1998). In the hills of Meghalaya, sacred groves reflect and epitomized a tradition, lifestyle and belief which are intrinsically linked to nature and its conservation (Myers, 1988; Shiva, 1992). Since there is minimal exploitation of these groves, they are a home to a number of flora and fauna. Therefore they are the best habitats for the reproduction of species and serve as propagates required for colonization of wastelands and fallow land.

Recent studies were conducted in sacred groves of Meghalaya have focused on the existence of such forests, their spread in the state and extent, current status, biology content and cultural ethos associated with them (Tiwari *et al.*, 1999). Different tree species tend to establish in different soil. But trees themselves also affect the chemical and microbial properties of soil. Disturbance of soil and alternation in plant cover may affect the distribution, size and activity of soil microorganisms and their ability to perform the biogeochemical cycles which are the important cycles for the cycling of essential nutrients. A number of soil microbiological parameters, notably microbial biomass carbon and basal respiration (Sparling, 1997), have been employed in national and international monitoring programmes. Soil microbial biomass can be further an important pool of plant nutrients and is often highly correlated with the organic matter content of soils (Pankhurst *et al.*, 1995). Consequently, a close relationship has also been reported between soil fertility and microbial biomass (Brookes, 1995). The enzymes also carry out

most of the biological processes, knowledge about enzyme activity and their variation in soil has considerable biological significance. Soil enzyme activity is often used as an index of microbial activity in soils as well as their fertility.

Little is known about the importance of the soil microbial communities for the sustained functioning of terrestrial ecosystem (Beare *et al.*, 1995; Moore *et al.*, 1995 and Pankhurst *et al.*, 1996). Studies on microbial diversity are important in order to understand the microbial ecology in soil and other ecosystems (Atlas, 1984). A number of studies on soil microorganisms have been done related to changes in community structure of microorganisms in agricultural soil, tropical, subtropical humid forest and temperate forest soils (Giller *et al.*, 1997). Microbiological studies in soil of sacred grove forest are still in its infancy and no comprehensive study has so far been made to explore and conserve the microbial diversity as a whole. In particular our knowledge of soil microbiology in sacred grove forest of Meghalaya is still meager. Therefore, such studies are needed to explore not only new fungal and bacterial diversity but also to gather knowledge on their substrate relationship, cultural and physiology, seasonal variations, quantitative estimations etc. Understanding of the seasonal variations in fungal and bacterial population has a paramount importance due to its relevance in biodiversity (Kennedy and Smith, 1995) and in regulating population of other organisms and ecosystem processes (Reid, 1994). Therefore the aim of this research was to evaluate diversity of fungi and bacteria, activity, biomass of soil microbial community and soil physico-chemical characteristic in sacred groves. This study will be helpful in gathering knowledge on the soil microflora

in sacred groves and this information may be of use to present day and future microbiologist who would be interested in the microbial diversity of this region. By keeping the various aspects as depicted above, the research has been carried out under the following heads:

1. Study of soil microbial diversity in the sacred groves.
2. Isolation and maintenance of soil microbes.
3. Analysis of physico-chemical properties of soil (moisture content, pH, organic C, N, P and K.
4. Study of microbial enzymes (Dehydrogenase, urease and phosphatase) and microbial biomass.

1.2 REVIEW OF LITERATURE

SOIL MICROORGANISMS

The microbiological analyses of soil provide a sensitive index of fertility and the relative numbers of bacteria, actinomycetes and fungi, and also indicate the chemical composition of the soil (Waksman, 1927). Considering their importance, various workers have studied the microbial population in soil and also indicated that soil factors such as acidity and temperature play an important role in the distribution of fungal species (Warcup, 1951).

The ecological factors like organic matter, pH, moisture content, aeration, temperature, soil depth, season and state of litter decomposition govern the distribution of microbes in soil (Mishra, 1966). Spatial and temporal

variations in soil microbial populations are well known from viable counts and direct microscope observations (Hattori, 1973; Alexander, 1977)

Donald and Whittingham (1978) compared the soil micro-fungal population in disturbed and undisturbed forests in northern Wisconsin and found out that there were differences in the population composition of the disturbed stands when compared with the undisturbed stands. Most of the differences were alterations in frequency and or density, although there were some conspicuous differences among the relative few predominant members of the populations. The environmental conditions in the disturbed forests apparently enhanced the competitive ability of some species, while that of the other species were impeded. According to them the interrelationships of vegetation and soil disturbance and seasonal changes on microbial enzymatic activities have not been studied. Spatial and temporal variations in soil microbial populations are well known from viable counts and direct microscopic observations (Soderstrom, 1979).

Alexander (1980) showed that the activity of many common bacteria is inhibited or suppressed by strong acidic conditions in soils but the relative abundance of fungi rises at lower pH because of their tolerance to acidity and through reduced competition from other microorganisms.

Rai and Srivastava (1981) have investigated the microbial population of the tropical dry mixed deciduous forest soil at Varanasi in relation to soil respiration and have observed a direct correlation between increase of microbial population and their activity, particularly in the case of fungi and actinomycetes.

Kauri (1982) studied the seasonal fluctuations in numbers of bacteria in beech forest soil and observed two peaks in bacterial population; one in autumn after leaf fall and another in spring.

Behera and Mukerji (1985) studied the seasonal variation and distribution of microfungi in forest soils of Delhi and noted that surface soils harboured the highest population and species number which gradually declined with increase in depth.

Molope *et al.* (1987) have shown that the microbial community is important in maintaining aggregate stability in soil, with fungi enmeshing soil particles in hyphae and bacteria secreting polysaccharides.

Tiwari *et al.* (1987) have reported wide differences on distribution of microbial populations, their activities and biochemical transformations in soils of various moisture regimes. They found significant variation in fungal population with different moisture contents. They concluded that soil moisture status not only regulates the population and activity of microbes but also modifies the relationship between various parameters.

Soil microorganisms play an essential role in the sustainability of indigenous forest ecosystems. Their function in nutrient cycling and their capacity to serve as a relatively labile source of nutrient elements in soil, in general, are well recognized (Duxbury *et al.*, 1989; Singh *et al.*, 1989). Many soil microorganisms are known to be intolerant to low soil moisture contents (Paul and Clark, 1989). Tiwari *et al.* (1989) reported that soil moisture

significantly alters the microbial population, its activity and relationship between parameters.

Climate varies between sites, influencing soil temperature and moisture regimes, which, in turn, influence the dynamics of soil microbial communities (Wardle and Parkinson, 1990). Hawksworth and Mound (1991) pointed out that most soil microbes cannot be isolated in culture and identified.

Wardle (1992) suggested that the temporal dynamics of the soil microbial community are likely to be important in determining the mineralization and hence availability of nutrients for plant productivity.

Kaiser *et al.* (1992) showed that the size and activity of the microbial populations depend on quantity and quality of soil organic matter, soil texture, soil pH and other properties of soil.

Diaz – Ravina *et al.* (1993) studied microbial populations in Spain, with a Mediterranean climate. They found that populations were lowest in the summer and winter, presumably due to moisture in summer and temperature in winter.

Zvyaginstev (1994) studied management in case of the forest and suggested that soil properties which change with soil depth control the composition of microbial populations.

Zhang and Zak (1995) studied patterns in microbial community dynamics in forest soils that are presumably related to the distribution patterns and types of vegetation in those forests. In spite of the many studies conducted to date, the importance of the ratio of fungi to bacteria as it relates

to soil microbial community function and terrestrial ecosystem function remains unclear.

Conyers *et al.* (1995) proposed that changes in temperature and water potential determine changes in microbiological activity, which in turn determines changes in the H^+ budget and its physicochemical consequences. Lima *et al.* (1996) showed that the bacterial populations increased as a function of sewage sludge and phosphate application. Fungal population was not affected by the application of phosphate alone but was increased by the application of sewage sludge.

Giller *et al.* (1997) hypothesized that reduction in soil microbial diversity will result in reduction in the functional capability of soil. Hawksworth and Rossman (1997) estimated 1.5 million fungal species in existence and only 5 - 10% has been formally described.

Garland (1997) observed that microbial communities have great potential for temporal or spatial change and thus represent power tool for understanding community dynamic variation in microbial community structure, which may effect on ecosystem process. The specific impact of soil management, seasonal conditions affect an amount of soil microbial activity as well as enzymatic activities (Batra *et al.*, 1997). It has been suggested that plants determine the composition and activity of a soil microbial community (Wardle *et al.*, 1997).

The soil microbial community is essential for the decomposition of organic material produce during primary production. The pool of soil carbon is

about twice as large as the atmospheric and any change of microbial activity could therefore have a profound influence on present global warming (Schlesinger, 1997).

Tiwari and Sharma (1998) reported that the fungal and bacterial populations in highland soils increased with increase in altitude upto 1100m, but thereafter, the populations declined sharply. They also observed positive correlations between fungal and bacterial populations with organic matter content of the soil.

Frey *et al.* (1999) mentioned that microbial community composition might be important determinant of soil organic matter decomposition rates and nutrient turnover and availability in agricultural soils. Taylor *et al.* (2002) stated that knowledge of microbial numbers and activity in sub-soils is essential for understanding the transformation and downward movement of natural and synthetic organics.

Hu *et al.* (1999) reported that bacterial response to alteration in C availability is important in understanding the microbial community structure and microbial interactions in soil ecosystem. Buckling *et al.* (2000) believed that fungal diversity can be increased by the patchiness of the environment and niche availability without imposing catastrophic species loss.

Arunachalam *et al.* (1999) reported in their studies that composition of the soil microflora, their biomass and their activity were greatly influenced by soil properties, particularly nutrient status. Disturbances like tree cutting, shifting cultivation, artificial plantation caused depletion of soil nutrients and

hence the microbial biomass and microbial activity were lower in the degraded sites than in the mature forests.

Liu *et al.* (2000) stated soil moisture, soil temperature, and/or substrate availability as the most important factors that influence soil microbial growth and population density. Soil microbial diversity (as measured by substrate utilization) and activity were generally reported to decrease with disturbance.

Klose *et al.* (2004) suggested that variations in amount and quality of the litter produced by each stand contributed to the responses of microbial and biochemical properties of the four studied forest site.

PHYSICO-CHEMICAL CHARACTERISTICS OF SOIL

The physico-chemical characteristics of soils can directly influence the structure, spatial distribution and activity of microbial population and enzymes in soils, which are potential early indicator of soil health and quality (Schnurer *et al.*, 1985; Dick, 1994). The differentiation between the different pools of enzyme activities in soils is important, because enzyme activities of microbial biomass can be used as indices of nutrient cycling and the health of different ecosystems (Klose and Tabatabai, 1999). Soil microbial populations may act as early indicators of changes in soil quality as they can respond much rapidly than soil C or N (Kennedy and Papendick, 1995). It contributes to the maintenance of soil quality through decomposition, nutrient cycling and availability and soil aggregation.

The physical condition and chemical characteristics of soil play an important role in determining the environment in which biological processes

take place and can be defined at different spatial and temporal scales (De Vos *et al.*, 1994). So the physico-chemical properties can determine the suitability of a soil for production of different crop plants (Brady, 1995). The chemical characteristics make a significant contribution in determining the quality and may even determine the maximum quality of a particular soil (Hassink, 1997).

Nutrients in soil exist mostly in organic and inorganic form, both of which are important source of plant and microbial uptake (Lyons *et al.*, 1998). The soil P availability is controlled by environmental conditions such as soil organic matter, moisture content and aeration, which influence microbial activity and eventually transformations of phosphorus (Hedley and Stewart, 1982; Bloom *et al.*, 1985; Read, 1991).

Microbial activity is a central factor in the soil organic phosphorus cycle (Stewart and Sharpley, 1987). Miller (1990) revealed that the soil organisms have a key role in the cycling and availability of nutrients required by the biological systems, the formation of soil organic matter decomposition of organic residues and detoxification of soil contaminants.

Nandelhoffer *et al.* (1991) and Holmes and Zak (1994) reported that an increase in microbial population can lead to nutrient immobilization and therefore decrease the availability of nutrients to higher plants. However, an increase in microbial activities can lead to an increase in net mineralization and therefore an increase in nutrient availability to the plants. Diaz- Ravina *et al.* (1993) showed that microorganisms contained substantial amounts of both C and inorganic nutrients and their contribution to the pool of available

nutrients was large for N, important in the cases of P, K and Mg and not significant for Na.

Juo *et al.* (1995) reported that when forest land was cleared there was no change in soil pH, at least until 13 years of bush re-growth. Different tree species tend to establish in different soils, but trees themselves also affect the chemical and microbial properties of soil. Spruce species have been shown to decrease the soil pH and slow down the cycling of nutrients, leading to the formation of mor humus (Micola, 1985). Whereas birch species may raise the pH, enhance the cycling of nutrients and lead to mull humus. (Miles and Young 1980; Bradley and Fyles, 1995).

Powlson *et al.* (1987) reported that organic matter as well as quality and activity of microorganisms represent sensitive indicators of soil genesis. Microbial activity in forest soil has great impact on forest growth. In forests with a low microbial activity large amounts of nutrients will accumulated in the mor layer in forms unavailable to the plants Berg *et al.*, 1995; Vesterdal *et al.*, 1995).

Jha *et al.* (2001) observed maximum moisture content in august and the least moisture in May. They found that during January, February, July and August moisture content decreased with increasing soil depth while in remaining months moisture content increased with increasing soil depth.

Lehmann (2001) stated that soil nutrient availability was not only related to the amount of nutrient applied but was also influenced by the tree

species. Nutrient return by litter fall and litter quality played an important role in soil P dynamics.

MICROBIAL BIOMASS C (C_{mic})

Jenkinson and Powlson (1976), Ayanaba *et al.* (1976), Anderson and Domsch (1978) and Brookes *et al.* (1982) reported that recognition of the importance of soil microorganisms in the functioning of ecosystem has led to an increased interest in measuring the nutrients held in soil biomass. According to Brookes *et al.* (1985) microbial biomass in soil is a relatively large and a labile component of organic matter containing important plant nutrients, especially N and P.

Smith and Paul (1990) found that there often is a close relationship between the size of the soil microbial biomass and the soil's organic carbon content, although the underlying mechanisms for this relationship are less well understood (Anderson and Domsch, 1986).

An increase in the size of the microbial biomass is considered essential for the improvement of soil because the larger the amount of biomass, the greater will be the potential availability to higher plants (Stevenson, 1986).

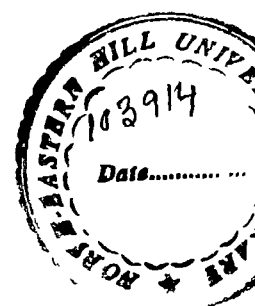
Microbial biomass C reflects the long term amount of C input into a soil (Mc Gill *et al.*, 1986; Anderson and Domsch, 1986). Jenkinson *et al.* (1987), McCaskill and Blair (1988) suggested that estimation of pool sizes of microbial C and N are therefore, required for many multi-compartmental models of nutrients dynamics in different ecosystems.

Estimation of soil microbial biomass is now frequently made, because of the importance of soil organisms in nutrient cycling and their role as a source and sink of plant nutrients (Jenkinson, 1988; Smith and Paul, 1990). Insam *et al.* (1989) and Insam (1990) found a close relation of microbial biomass and the microbial biomass: organic C ratio with several climatic variables.

Nannipieri *et al.* (1990) hypothesized that since microorganisms are considered the primary source of enzymes of soils, enzyme activities are strongly associated with the active microbial biomass and its metabolic state. A measure of the size of the soil microbial biomass is of importance in studies of nutrient cycling in soils and has been used as an ecological marker (Smith and Paul, 1990). However, detailed information on qualitative changes of soil organic matter during the seasons is still lacking (Andreux *et al.*, 1990).

Wardle (1992) stated that most of biomass consists of bacteria and fungi with the balance consisting of soil microflora and algae. Amount of microbial biomass is influenced by soil texture and quality of soil organic matter.

Soil microorganisms such as bacteria and fungi play a major role in releasing CO₂ by metabolizing organic debris. Anderson and Domsch (1993) reported that the biomass is the most important indicator of microbial performance in soil, especially in combination with an activity parameter such as CO₂ production.



Ravina *et al.* (1993) reported that in the forest soils, the soil microorganisms immobilize relatively high amounts of nutrients in their biomass; the concentration of the microbial biomass to soil concentration of available plant nutrients was large for N, P and K.

Henrot and Robertson (1994) in their studies demonstrated the dynamic nature of microbial biomass following tropical forest clearing and its potential importance for affecting soil fertility since microbial biomass represents an important labile pool of soil nutrient and may play an active role in preventing nutrient losses. Decline of microbial biomass may provide an early indication for slower, less easily detectable soil organic matter changes.

A number of soil microbiological parameters notably microbial biomass carbon and basal respiration (Doran and Parkin, 1994) have been suggested as a possible indicator of soil quality and have been employed in national and international monitoring programmes. Soil microbial biomass can be an important pool of plant nutrients and is often highly correlated with the organic matter contents of soils (Pankhurst *et al.*, 1995)

Maithani (1996) revealed that the values of microbial biomass could provide one of the most satisfactory estimates of the restoration of soil microbial populations.

Bolter *et al.* (2002) stated that number and biomass of microorganisms as well as descriptions and monitoring of microbial communities are basic requirement for understanding microbiological processes, thus they are within the remit of soil ecological research.

Soil microbial biomass is a non specific but integrative measure of the physiologically active part of the soil microflora (Bailey *et al.*, 2002). Due to the crucial role of soil microorganism in nutrient cycling (Nannipiri *et al.*, 2002), the study of soils microbial function can provide important information when evaluating soil remediation.

Soil microbial biomass is a non specific but integrated measure of the physiologically active part of the soil microflora (Bailey *et al.*, 2002). The microbial carbon has been widely used as an approach to evaluate soil quality (Gil- Soteres *et al.*, 2005).

SOIL ENZYMES

Numerous investigations into the activity of enzymes in agricultural sites (meadow, pasture land, aerable land) have been carried out (Ross and Cairns, 1982; Frankenburger and Dick, 1983; Sarathchandra *et al.*, 1984; Nannipieri, 1984; Speir *et al.*, 1984; Stott *et al.*, 1985). However, there is little information available about enzyme activity in forest soils. (Stott and Hagedorn, 1980; Harrison, 1983; Huttermann *et al.*, 1983; Rastin *et al.*, 1984).

Soil enzymes activities are 'sensors' of soil degradation. Since they integrate information about microbial status, and also, from soil physico-chemical conditions (Wick *et al.*, 1998; Aon and Colaneri, 2001., Baum *et al.*, 2003), they are used as sensors in studies on the influence of soil treatments on soil fertility and they may correlate well with nutrient availability (Chen *et al.*, 2003).

Bacteria and fungi synthesize and secrete enzymes such as phosphatases, proteases, ureases and pectinases extracellularly. Those microbially secreted constitute an important part of the soil matrix as extracellular enzymes, also called abiotic enzymes (Sinsabaugh, 1994). Factors influencing soil microbial activity exert control over soil enzyme production and control on nutrient availability and soil fertility (Sinsabaugh *et al.*, 1993).

Soil enzyme activity showed considerable sensitivity to slight decreases in water availability. Decrease in soil enzymes and activities through soil profile have been observed in forest and agriculture sites when there are organic inputs in the soil surface (Aon and Colaneri, 2001, Chen, 2003; Chen *et al.*, 2003). Enzyme activities can vary depending on the sampling date in zones with a seasonal climate (Watanabe and Hayano, 1995; Baum *et al.*, 2003). In Mediterranean ecosystem, the highest activities occur in spring together with the most active growth of plants and microbial activity (Gracia *et al.*, 1997, 2002).

PHOSPHATASE

The phosphatases are involved in transformation of organic and inorganic phosphorus compounds in soil. Their activity may play a significant role in P availability to plants from native soil organic P compounds. Phosphatase activity measurements provide an index of potentially available phosphate in soil. Rogers *et al.* (1942) described that acid phosphatase, which is present in plant roots is predominant in acid soils and is responsible for the hydrolysis of organic phosphorus in soils.

Soil phosphatase activity and the general mineralization of organic P have been reviewed extensively (Cosgrove, 1967; Halstead and McKercher, 1975; Dalal, 1977 and Speir and Ross, 1978).

Skujins (1976) opined that phosphatase activity can be used to estimate the general microbial activity in soil. In soil ecosystems, phosphatase and arylsulphatase are believed to play pivotal roles in phosphorus and sulphur cycle respectively (Speir and Ross, 1978).

Burns (1978) reported that seasonal variation appears to be dependent on many factors, such as aeration, soil moisture, vegetations and microflora as well as soil temperature. The increased phosphates activity observed subsequently may be due to an increase on number of microorganisms.

Harrison and Pearce (1979) investigated the type and parent material in woodland soils. The results of their study demonstrated that intensity of phosphatase activity and soil properties differed with soil depth, soil type, season and vegetative type.

Malcolm, (1983) studied the assessment of phosphatase activity in soils and found that the use of optimum pH in enzyme activity measurements provides a measure of the maximum potential activity of the enzyme under natural conditions.

Harrison, (1983) found that phosphatase activity in woodland soils is related to soil physical and chemical properties such as soil pH, contents of nitrogen, organic matter (0-5 cm depth), moisture and plant-available phosphorus.

Trasar – Cepeda and Gil – Sotres (1987) studied phosphatase activity of acid soils with high organic matter content in forest soils. They found higher activity of acid phosphatase between pH 5 and 6, which appeared to depend on organic activity of soil suggesting that enzyme originating from litter was progressively inhibited as it penetrated the soil.

Baligar *et al.* (1988) found very close association between soil phosphatase activity and moisture content, organic C and ammonium N concentrations in acid soils of the Appalachian mountain.

There is a natural regulation of phosphates activity in soil in this activity is increasing when soil are depleted of available phosphorus. It is however, likely that under field condition soils always contain sufficient phosphates to hydrolyze any organic phosphorus compounds that is released by the soil. Enzymes in soil do not only originate from microbial sources, but also from animals and plant roots. The presence of plants positively affects enzymes activities including that of phosphates (Tadano *et al.*, 1993). Phosphatase activity can also be affected by earthworm and other soil animals (Satchel and Martin, 1984; Weiss and Trespendorfer, 1993).

Hoffman and Elias–Azar (1995) reported that the intensity of phosphatase activity in soils has been found to soil physical and chemical properties, such as soil pH, nitrogen contents, organic matter and plant available phosphorus.

Lyons *et al.* (1998) observed soil phosphatase, is mostly of plant and microbial origin and consists of alkaline and acid phosphatases. The lowest

enzyme activity was recorded in dry soils and this increased with increased in moisture content in soil at maximum moisture holding capacity.

DEHYDROGENASE

The activity of dehydrogenase is considered an indicator of the oxidative metabolism in soils and thus of the microbiological activity (Skujins, 1973), because, being exclusively intracellular, it is linked to viable cells. However, the relationship between an individual biochemical properties and the total microbial activity is not always obvious, especially in the case of complex systems like soils, where the microorganisms and processes involved in the degradation of the organic compounds are highly diverse (Nannipieri *et al.*, 1990). Dehydrogenase activity has been used as an indicator of the microbiological activity in Mediterranean arid soils (Garcia *et al.*, 1994) and in agricultural soils of more humid regions (Beyer *et al.*, 1992). It is thought to be an indicator of overall intracellular in all living microbial cells and is linked with microbial oxidoreduction processes (Quilchano and Maranon, 2002; Stepniewska and Wolinska, 2005).

Akbaba (1994) and Ozcelik (1996) claimed that enzymes are inactive above 50⁰ C. The highest and the lowest enzyme activities were obtained at 5 -10 cm and 0 -1 cm respectively. Lower enzyme activity at the top soil layer is probably due to the lower soil humidity.

Garcia *et al.* (1994) found that the rainy season enhanced the dehydrogenase activity of soils in the south east arid region of Spain. Other authors also contributed the increase in microbial activity in forest (Gorres *et*

al., 1998) and in grassland soils (Banerjee *et al.*, 2000) due to higher soil moisture content.

Lyons *et al.* (1998) observed soil phosphatase, the enzyme that transforms organic P to inorganic P is mostly of plant and microbial origin and consists of alkaline and acid phosphatases. The lowest enzyme activity was recorded in dry soils and this increased with increased in moisture content in soil at maximum moisture holding capacity.

Quilchano and Maranon (2002) have reported that dehydrogenase activity (DHA) measured in a forest soil in autumn samples was almost double that measured in summer samples at the same location. Significant differences were detected between the values of dehydrogenase activity in the two seasons. They also reported that the increase in soil water content in autumn would favour the increase in microbiological activity (and hence in DHA), especially considering the low water potential values measured in summer.

UREASE

Urease is a key component in the nitrogen cycle in soils because its substrate, urea is incorporated into soil as fertilizer, animal et cetera or a breakdown product of nuclei acid. Urease activity is found in a large number of soil bacteria and fungi (Sarathchandra *et al.*, 1984)

Although numerous studies of urease activity in soils have been reported (Skujins, 1967; Kuprevich and Shcherbakova, 1972), very little is known about the processes and factors affecting the level of urease in soils. It

is well established, however, that soil microorganisms can produce urease, and soil factors, such as moisture content, pH, organic matter and numbers of microorganisms affect the urease activity in soil. (Skujins, 1967).

Soil ureases are microbial products that can accumulate in cell free form in the soil because they are highly resistant to environmental degradations (Zantua and Bremner, 1977).

Speir (1977) observed a strong positive relationship between urease activity and soil pH. He also found that enzyme activities were correlated significantly with several soil chemical properties related to the amount of organic matter. Tabatabai (1977) studied on urease activity showed that it is concentrated in surface soils and decreases with depth. Urease activity was proportional to organic carbon distribution in soil profile and was significantly correlated with organic carbon.

Burn (1982) reported that urease activities were influenced by the type and density of vegetational cover, climate and soil type.

Rao and Ghai (1985) estimated the urease activity of alkaline and reclaimed soils. They found that urease correlated positively with organic C and N and negatively correlated with soil pH. They further, demonstrated that organic C may be accounted for most of the variations in enzyme activity.

Joshi *et al.* (1991) reported that soil with higher microbial population harboured higher urease activity.

Klose and Tabatabai (1999) also studied the relationship between urease and microbial biomass C and revealed highly significant relationship between urease activity and microbial biomass C.

Nourbakhsh and Monreal (2004) reported that there were no significant correlations between urease activity and soil textural properties, pH and bacterial and fungal populations.

1.3. STUDY SITES

The area of study was carried out at two sacred groves viz. Khloo Payung and Khloo Langdoh located within Jowai township area the head quarter town of Jaintia Hills district at an altitude of 1300 m asl, 25° 26' 32" N Latitude, and 29° 12' E Longitude. The sacred groves are located within a radius of 2 km in Jowai town. Khloo langdoh is surrounded by human habitation and occupies the crest of a gentle sloping hill. The forest is divided into two parts by construction of a motorable road. Khloo Paiung is on the east of Khloo Langdoh and located on the east and south east facing slopes of a hillock overlooking the river Myntdu or the Syntu Ksiar. The pine forest stand was also selected as control which is about 1km away from the two sacred groves.

Lithologically, Jowai falls in the formations of Jaintia series/ Disang series, which are made up of Syllhet sandstone consisting of sedimentary structures like wedge and festoon type of cross bedding, ripple marks and burrow markings (Sarma *et al.*, 1993). According to Evans (1934) these are tertiary beds characterized by hard sanstone (Ahmad, 1993), soft loose sand

hard conglomerates, sandstone, sandy shales and sandy clays. According to National Bureau of Soil Survey (NBSS) and Land Use Planning (ICAR), Nagpur, The soil of Jaintia hills belongs to Udalfs-Ochrepts-Fluvents-Orthents category.

The soil texture of the two sacred groves is sandy loam. The vegetation of the two sacred groves composed of both evergreen and deciduous broad leaved trees. The dominant plant species are *Castanopsis purpurella*, *C. tribuloides*, *Cinnamomum glanduliferum*, *Drimycarpus racemosus*, *Neolitsea cassia*, *Schima khasiana*, *Quercus kamroopii*, *Rhododendron arborium*, *Myrica esculenta*, *Ilex embelioides*, *Camelia caudate*, *Coffea khasiana*, *Ficus hirta*, *Turpina nepalensis*, *Erythroxylum kunthianum*, *Styrax serrulatum*, *Microtropis discolor*, *Wendlandia wallichii*.

1.4. CLIMATE

The climate of Meghalaya is humid and warm. The central upland experiences very cold night during winter where temperatures goes down to 1.7°C. There is a great variation of rainfall in the plateau. On the basis of prevailing weather conditions, four seasons in a year are normally recognized for the state as a whole. They are: winter season which is a cold season from December to end of February, spring or warm season from March to mid May, rainy season from mid May to September and autumn or cool season from October to November. Monthly rainfall pattern and mean maximum and minimum temperature during the study period is shown in Fig 1.1

1.5. SOIL SAMPLINGS

Soil samplings were collected from the study sites at bimonthly intervals from February 2002 to December 2003. In each sampling, soil were collected randomly by a soil sampler from different sites of the forest at different depths (0-10cm, 10-20cm and 20-30cm). The soil sample from each depth were mixed thoroughly to obtained a composite sample then kept in sterilized polythene bags. This was done to minimize local variation in the microbial populations. Various estimations were carried out within 24 hours of collection. Collections were done in aseptic conditions and the samples were brought to the laboratory on the same day and kept at 4°C until they were used.

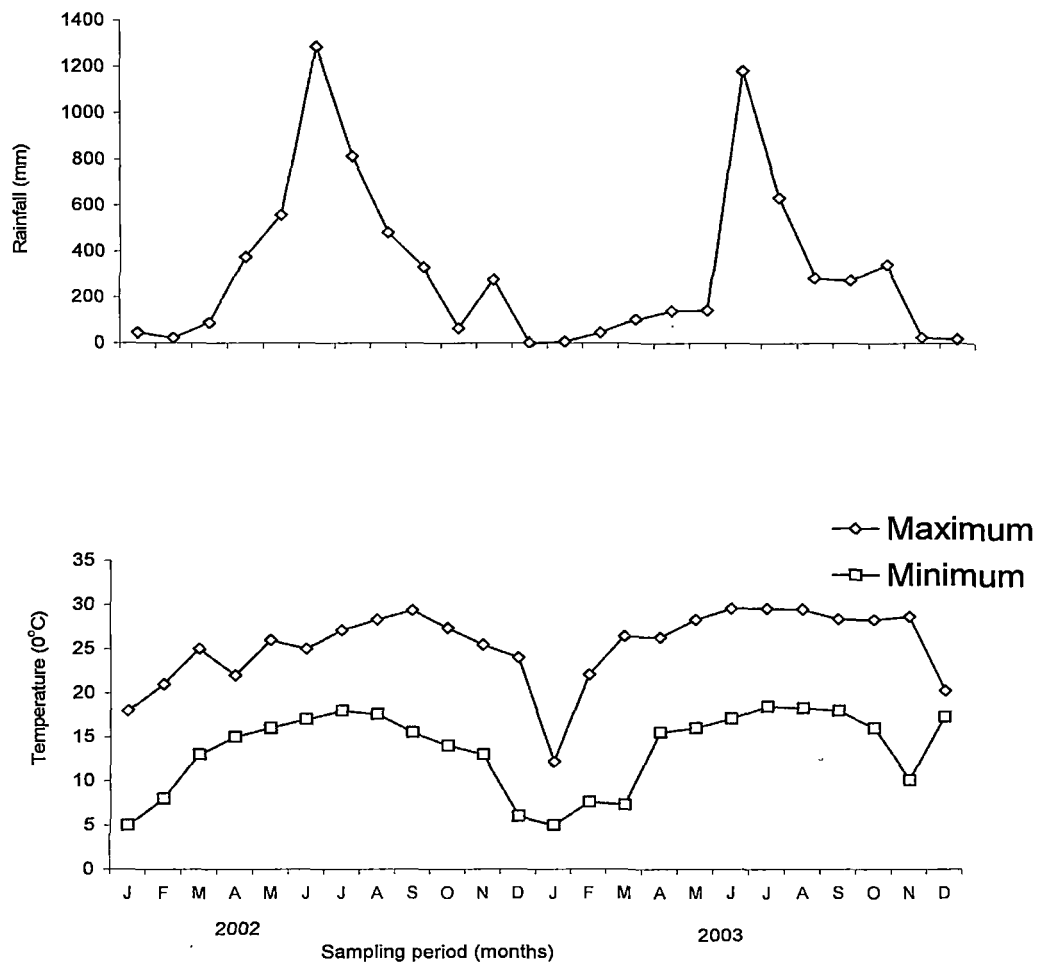


Fig 1.1 Monthly variations in rainfall and temperature of the study area.

CHAPTER 2

ENUMERATION OF SOIL FUNGAL AND BACTERIAL DIVERSITY IN TWO SACRED GROVES AND PINE FOREST

2.1. Introduction

Microbial diversity may be described as a measure of the range of insignificantly different kinds of microorganisms within a natural community or habitat. (Atlas, 1984). However, it has been argued that it is diversity at the functional level rather than at the taxonomic level that is important for the long term stability of an ecosystem (Walker, 1992). Microbial diversity studies are important in order to understand the microbial ecology in soil and other ecosystems (Atlas, 1984 and Reid, 1994), especially due to the fact that life is dependent on microbial processes. An estimate of microbial diversity is a prerequisite for understanding the functional activities of microorganisms in ecosystems (Garland and Mills, 1994; Žak *et al.*, 1994). Taxonomic approaches to estimating biodiversity of soil microbial communities are limited by difficulties in defining suitable taxonomic units and the apparent non-culturability of the majority of the microbial species present in the soil. The soil microflora and the vegetation of an ecosystem are closely interrelated. Plants influence biotic processes by delivering organic compounds, whereas soil microbes have an impact on plant growth by the decomposition and mineralization of plant material (Pietikainen, 1999; Bachman *et al.*, 2002).

Soil microorganisms are of great importance for soil ecosystems because they affect plant available nutrients and soil structural stability (Paul and Clark, 1989). The abundance, size and activity of the microbes depend on quantity and quality of organic matter, texture, and other environmental factors (e.g. soil type, nutrient status, pH and moisture) as well as plant factors e.g. species, age (Kaiser *et al.*, 1992). It is generally and widely accepted that microbial population size increases with the accumulation of soil organic matter (Jenkinson and Ladd, 1981). Buckley and Schmidt (2001), Chow *et al.*, (2003), Laiho *et al.*, (2003) reported that disturbance of the soil or substrate causes dramatic changes in the taxonomic and functional diversity of soil microbial communities.

Soil organisms collectively represent a relatively labile pool of C, N, P, and the rates of turnover of these elements through the microbial biomass have important consequences for nutrient flow (Jenkinson and Ladd, 1981; Rosswall and Paustian, 1984). Hackl *et al.*, (2004) reported that soil microorganisms represent essential components of the biotic system in natural forests where they are key players in nutrient turnover. As different functional groups of microorganisms respond differently to prevailing environmental conditions, forest stands characteristics (i.e. Soil and vegetation properties) influence the composition of the soil microbial community in a specific way. Thus, the greatest microbial diversity at small scale appears to reside in the soil and microorganisms are among the most complex, diverse and important assemblages in the biosphere diversity (Zhou *et al.*, 2003).

2.2. Methodology

2.2.1. Enumeration of fungi and bacteria

Serial dilution plate method (Waksman, 1922; Parkinson *et al.*, 1971) was followed for the isolation of fungal and bacterial populations. One gram of soil sample was taken into the 250 ml conical flask containing 100 ml of sterilized distilled water to give 1:100 dilutions. To prepare homogenous solution, the flask was swirled for 15 minutes. Then 10 ml of this solution was transferred to another flask containing 90 ml of sterilized distilled water with the help of sterilized pipette to get 1:1000 dilution, 10 ml of this solution was again transferred to another flask containing 90 ml of sterilized distilled water to get 1:10000 dilutions.

2.2.2. Fungal population

The rose bengal agar medium (Martin, 1950) was used for the study of fungal population. One milliliter of the soil dilution (1:1000) was transferred into a Petridish containing rose bengal agar medium, which was then rotated gently to disperse the suspension. Three replicates were maintained for each sample. The Petridishes were incubated upside down at $25 \pm 1^{\circ}\text{C}$ for 5 days in a BOD incubator. Colony form unit (CFU) of fungi was estimated by counting the number of fungal colonies. The CFU of fungi per gram soil was calculated on the dry weight basis.

$$CFU \text{ of fungi / g } D_w = \frac{\text{Number of colony form} \times \text{dilution factor} \times \text{inoculums}}{\text{Dry weight of soil the (g)}}$$

Where, D_w = Dry weight of the soil (g)

The fungal species were identified on the basis of their morphology and reproductive structures, consulting monographs by Subramanian (1971), Barnett and Hunter (1972) and Domsch *et al.* (1980). The following formula was used for the determination of relative abundance of fungal species:

$$\text{Relative abundance (\%)} = \frac{\text{Total number of the colonies of individual species}}{\text{Total number of colonies of all species}} \times 100$$

Rose Bengal Agar medium (Martin, 1950):

Agar	20 g
KH ₂ PO ₄	10 g
MgSO ₄ .7H ₂ O	0.5 g
Peptone	5 g
Dextrose	10 g
Rose bengal	3.3 ml
Streptomycin	30 mg
Distilled water	1000 ml

2.2.3. Bacterial population

Nutrient agar medium (Difco manual, 1953) was used for the isolation of bacterial species. 0.5 ml of the soil solution from 1:10000 dilutions was transferred to a petridish containing nutrient agar medium. Three replicates were maintained for each sample. The plates were rotated to disperse the suspension uniformly. The inoculated plates were then incubated in upside down position at 30±1° C in bacteriological incubator. Colony form unit (CFU)

of bacteria was estimated by counting the number of bacterial colonies. The CFU of bacteria per gram soil was calculated on the dry weight basis.

$$CFU \text{ of bacteria / g } D_w = \frac{\text{Number of colony form} \times \text{dilution factor} \times \text{inoculum}}{\text{Dry weight of the soil (g)}}$$

Where, D_w = Dry weight of the soil (g)

The following formula was used for the determination of relative abundance of bacterial species:

$$\text{Relative abundance (\%)} = \frac{\text{Total number of the colonies of individual species}}{\text{Total number of colonies of all species}} \times 100$$

Nutrient agar medium (Difco manual, 1953):

Agar	15g
Beef extract	3 g
Peptone	5 g
NaCl	8 g
Distilled water	1000 ml

(The final pH of the medium was adjusted to 7.3).

2.2.4. Statistical analysis

Using the data obtained the following indices of fungi and bacteria species structure assessed.

(1) Index of general diversity (H'); Shannon and Weaver (1949) cited in Odum (1971).

$$H' = -\sum (n_i / N \log_e n_i / N)$$

(2) Index of similarity (Sorensen) S , (1989)

$$S = \frac{2C}{S_1 + S_2}$$

Where, S_1 = the number of species in one site 1

S_2 = the number of species in one site 2

C = the number of species that are common to both site 1 and site 2.

2.3. Results

2.3. 1. Fungal population

The colony form unit (CFU) of fungi varied in all the forest stands though it increased in both sacred groves. The fungal population in most cases was high at the surface soil layer (0-10cm) than at the sub surface soil layer (10-20 and 20-30cm)

In the first year (2002) of study maximum fungal population was obtained during rainy season in June and October 2002 in Khloo Paiung and Khloo Langdoh respectively and minimum during winter in February and

December 2002 for all the forest stands. In the second year maximum fungal population was recorded in April and August 2003 in Khloo Paiung and minimum during December 2003 in all the three forest stands (Fig. 2.3.1).

The analysis of variance (ANOVA) showed significance variation at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in pine forest whereas in Khloo Paiung it showed significance variation at 0-10cm x 10-20cm x 20-30cm and 10-20cm x 20-30cm and in Khloo Langdoh at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm (Tables 6.1, 6. 2 and 6. 3).

The correlation coefficient indicated that in Khloo Paiung, fungal population showed positive correlation with total nitrogen, organic carbon, urease activity, dehydrogenase, moisture content and bacterial population (Table 6.5). In Khloo Langdoh it showed positive correlation with total nitrogen, microbial biomass carbon, moisture content and bacterial population (Table 6.6). In pine forest it showed positive correlation with total nitrogen, organic carbon, microbial biomass carbon, dehydrogenase, phosphatase activity moisture content and bacterial population (Table 6.7).

The total list of fungal species isolated during the study period is 90 fungi and 5 sterile mycelia (Table 2.3.1). 75 fungal species isolated from Khloo Paiung sacred grove, 66 fungal species from Khloo Langdoh and 59 fungal species from Pine forest. 54 species are common to both the sacred groves, 46 species are common to Khloo Paiung and Pine forest, while 39 species are common to Khloo Langdoh and Pine. The highest relative

abundance of fungi was *Aspergillus flavus* in Khloo Paiung, *Verticillium chlamydosporium* in Khloo Langdoh, and *Trichoderma koningii* in pine forest (Tables: 2.3.3 - 2.3.11). Shannon Diversity index of fungal species in the first year (2002), at surface soil layer (0-10cm) it ranged from 1.70 to 2.44 in December and October in pine forest and Khloo Paiung respectively. At sub-surface soil layer (10-20cm) it ranged from 1.62 to 2.35 in October and June in Khloo Paiung respectively. At 20-30cm it ranged from 1.54 to 2.15 in February and June in Khloo Paiung respectively (Fig.2.3.3).

In the second year (2003), at surface soil layer (0-10cm) Shannon Diversity Index of Fungi ranged from 1.59 to 2.51 in December at Khloo Paiung and Khloo Langdoh respectively. At sub surface soil layer (10-20cm) it ranged from 1.55 to 2.68 in June and August 2003 in Pine and Khloo Langdoh respectively. At 20-30cm it ranged from 1.25 to 2.74 in April and August at Khloo Langdoh and Khloo Paiung respectively (Fig. 2.3.4).

Sorenson Similarity index displayed a similar result throughout the investigating period, at 0-10cm it ranged from 0.56-0.58 at 10-20cm it was from 0.45-0.48 and at 20-30cm it was 0.44-0.57 (Fig. 2.3.7).

2.3.2. Bacterial population

The colony form unit (CFU) of bacteria increased during the rainy months in all the three forest stands. The maximum bacterial population in the first year of study was recorded in June 2002 for Khloo Langdoh and pine forest and in August 2002 for Khloo Paiung. Minimum bacterial population

was recorded in February 2002 for all the three forest stands. In the second year of study the maximum bacterial population was in June 2003 for all the three forest stands. Minimum bacterial population was in August 2003 in pine forest (Fig: 2.3.2.).

Between the sampling periods the bacterial population declined with soil depths. It was higher at the surface soil layer (0-10cm) and lower at the sub surface layer (10-20cm, 20-30cm). The analysis of variance (ANOVA) showed significance variation of bacterial population at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in pine forest and Khloo Paiung whereas in Khloo Langdoh it showed significance variation at 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm (Tables 6.1, 6.2 and 6.3).

Altogether, 8 bacterial species were isolated (Table 2.3.2). *Microccus* sp, *Arthrobacter* sp and *Rhizobium* sp were the dominant species. The highest relative abundance of bacteria was *Microccus* sp in Khloo Paiung, *Bacillus subtilis* in Khloo Langdoh, and *Arthrobacter* sp. in pine forest (Tables: 2.3.12 - 2.3.20). The bacterial population showed positive correlation with moisture content, organic carbon, total nitrogen, available phosphorus, dehydrogenase phosphatase and fungal population in Khloo Paiung (Table 6.5). In Khloo Langdoh the bacterial population showed positive correlation with moisture content, organic carbon, total nitrogen, microbial biomass carbon, dehydrogenase, urease and fungal population (Table 6.6). In pine forest the bacterial population showed positive correlation with total nitrogen,

microbial biomass carbon, urease, phosphatase and fungal population (Table 6.7).

Shannon Diversity index of bacterial species in the first year (2002) at surface soil layer (0-10cm) ranged from 0.49 to 1.70 in April and October 2002 in Khloo Paiung. At sub surface soil layer (10-20cm) it ranged from 1.01 to 1.75 in April and June in Khloo Paiung. At 20-30cm it ranged from 0.64 to 1.76 in April and October 2002 at Khloo Paiung (Fig. 2.3.5). In the second year (2003) at surface soil layer (0-10cm) Shannon Diversity Index, ranged from 0.68 to 1.69 in August 2003 at pine forest and Khloo Langdoh. At sub surface soil layer (10-20cm) it ranged from 0.63 to 1.88 in October and February 2003 in pine forest and Khloo Paiung. At 20-30cm it ranged from 0.92 to 1.66 in October and August 2003 at pine forest and Khloo Paiung respectively (Fig. 2.3.6). Sorenson Similarity index displayed a similar result throughout the investigating period ranging from 0.85-1 (Fig. 2.3.7).

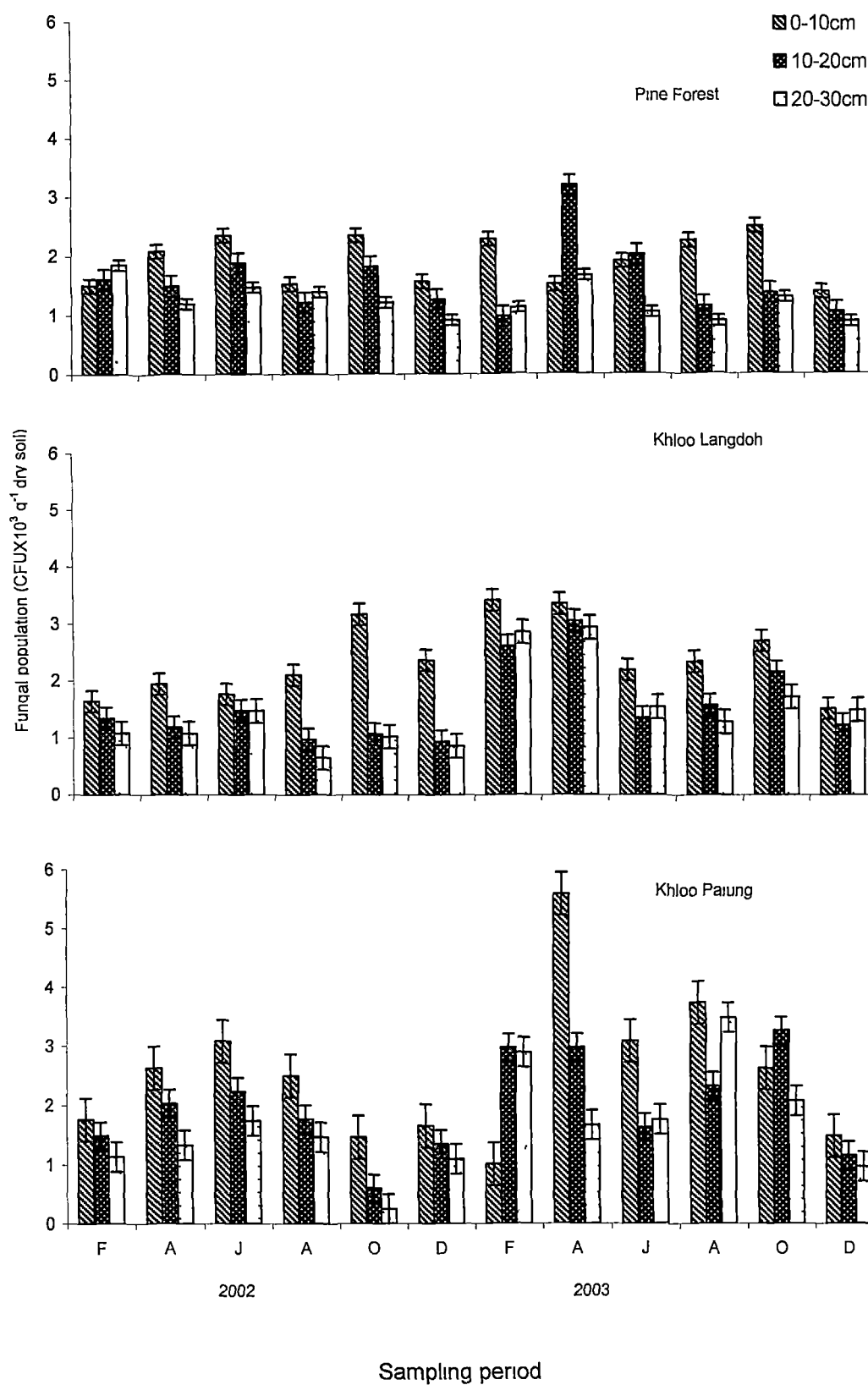


Fig. 2.3 1 Bimonthly variation of fungal populations (0-10 cm, 10-20 cm and 20-30 cm depths) in two Sacred Groves and Pine forest

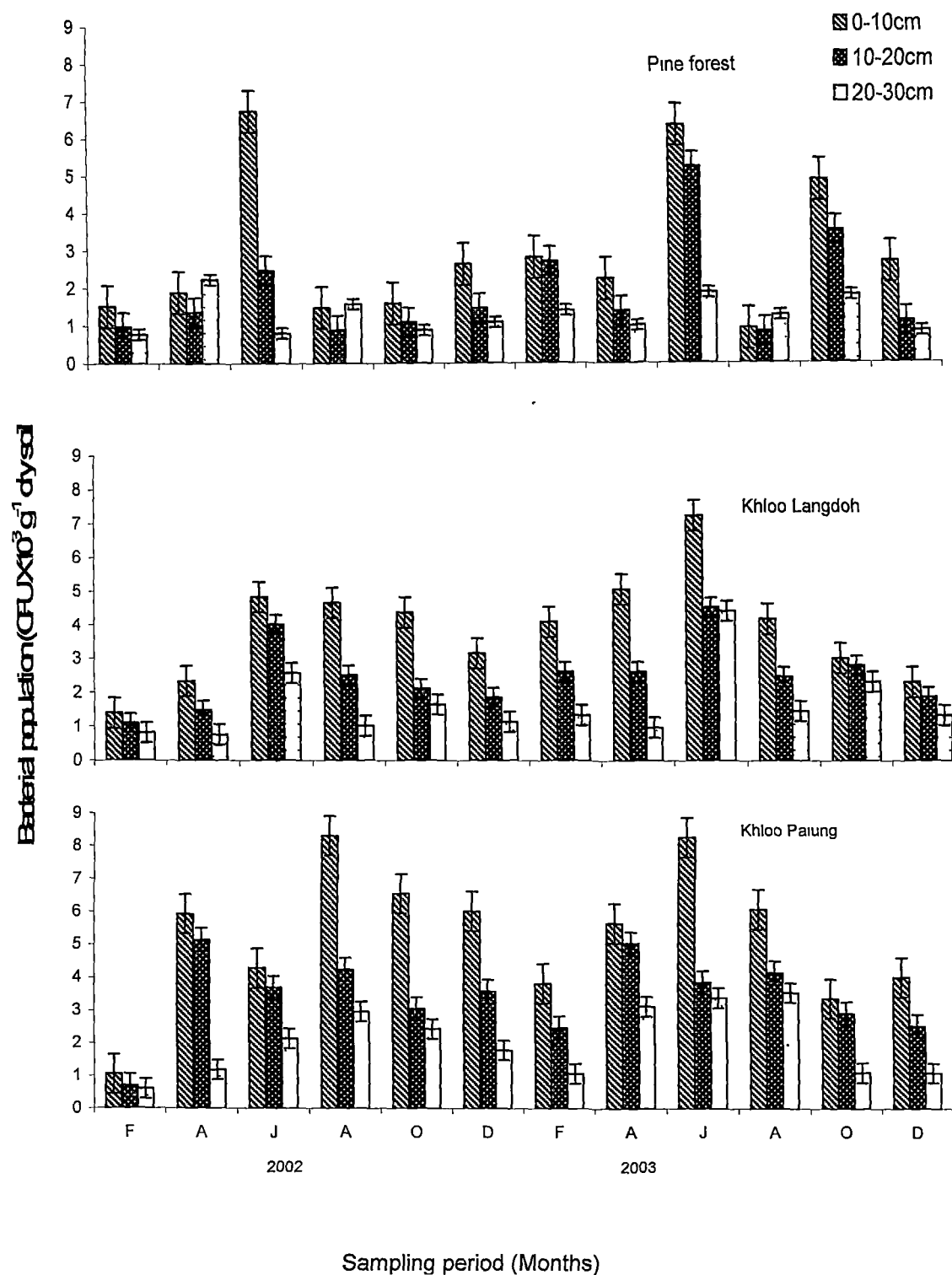


Fig: 2 3 2 Bimonthly variation of bacterial populations (0-10 cm, 10-20 cm and 20-30 cm depths) in two Sacred Groves and Pine forest

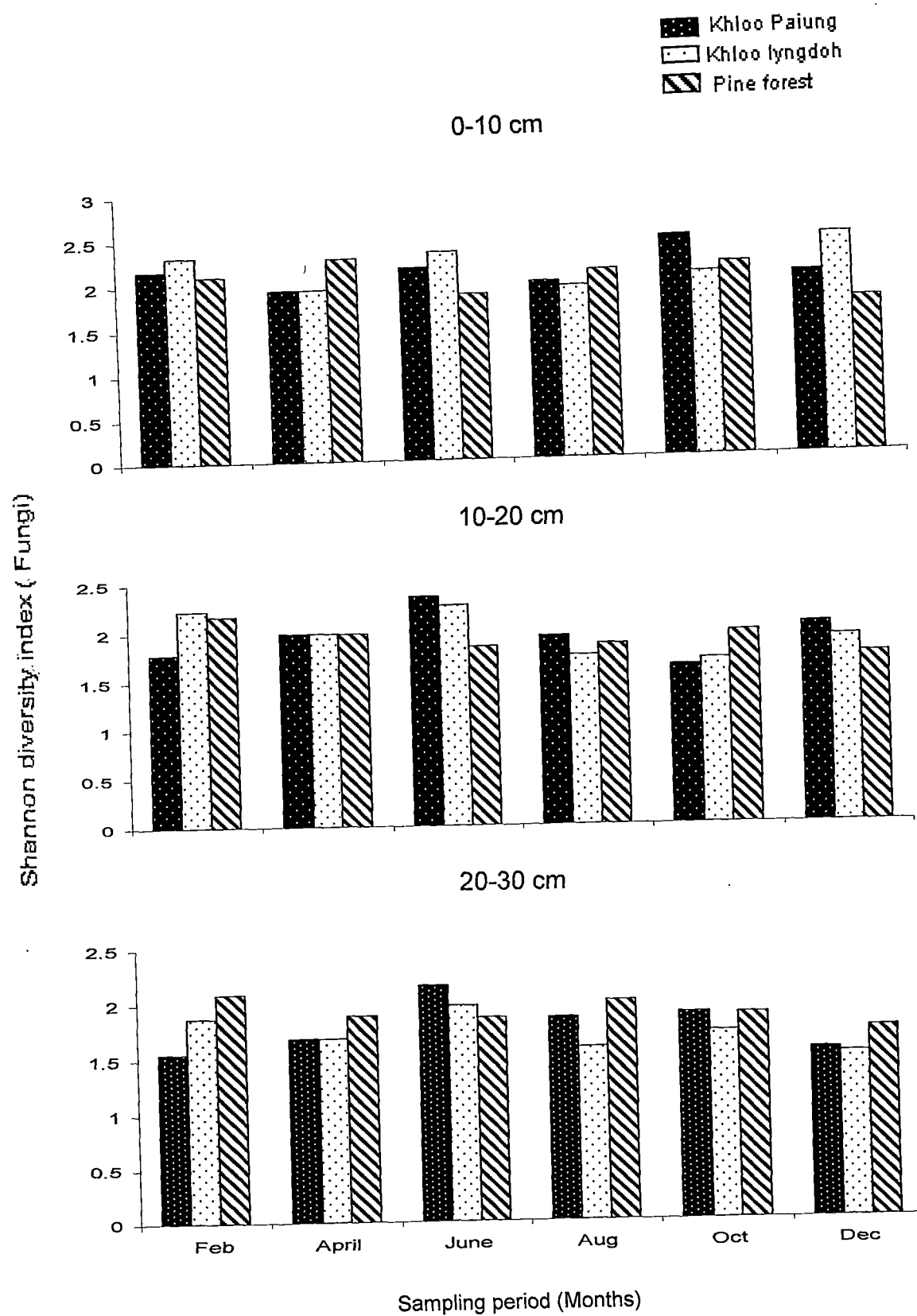


Fig. 2.3.3. Shannon diversity index of fungi in soil (0-10 cm, 10-20 cm and 20-30 cm depths) during 2002 in two Sacred Groves and Pine forest

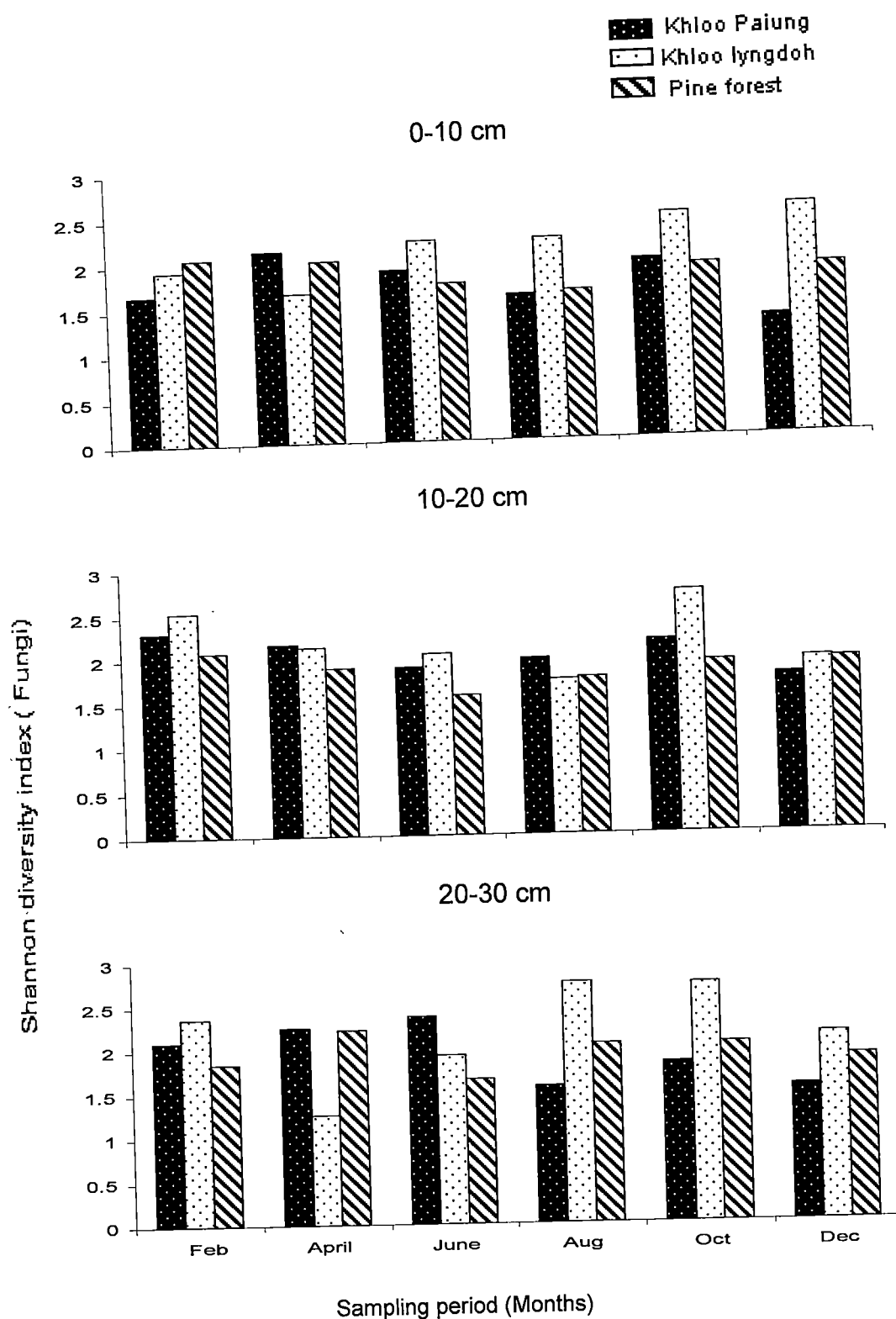


Fig.2.3.4. Shannon diversity index of fungi in soil (0-10 cm, 10-20 cm and 20-30 cm depths) during 2003 in two Sacred Groves and Pine forest

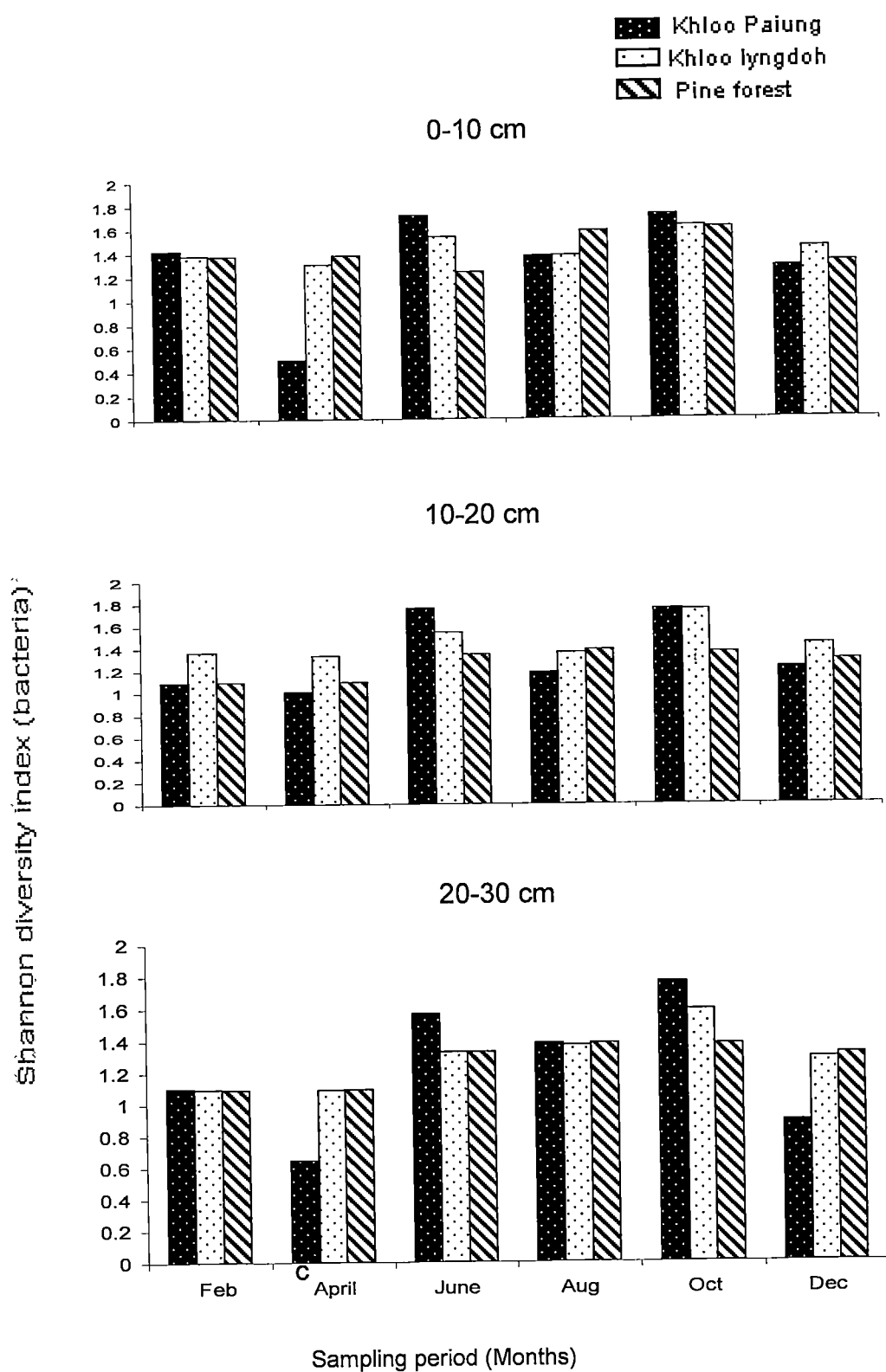


Fig.2.3.5. Shannon diversity index of bacteria in soil (0-10 cm, 10-20 cm and 20-30 cm depths) during 2002 in two Sacred Groves and Pine forest.

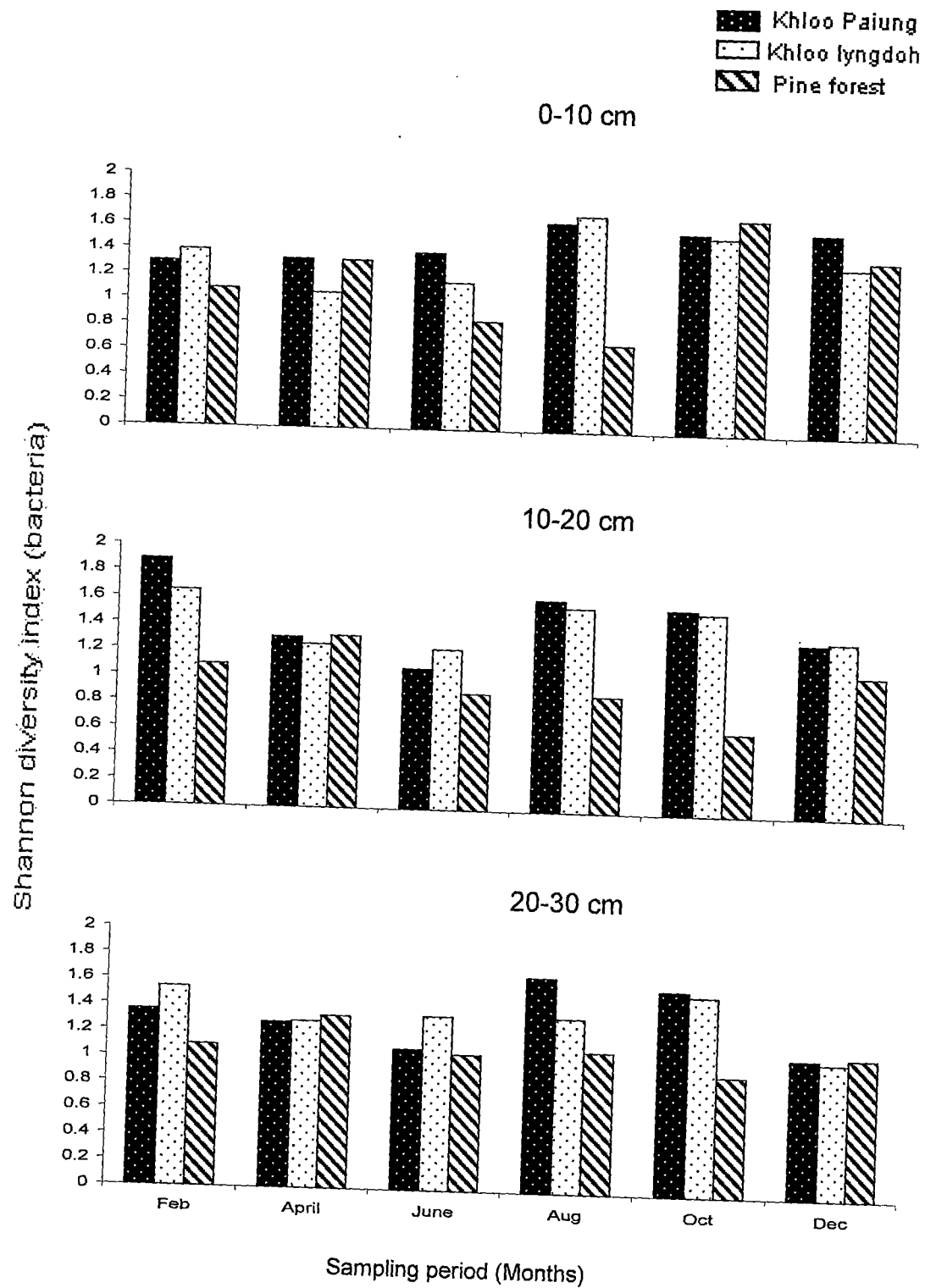


Fig.2.3.6. Shannon diversity index of bacteria in soil (0-10 cm, 10-20 cm and 20-30 cm depths) during 2003 in two Sacred Groves and Pine forest.

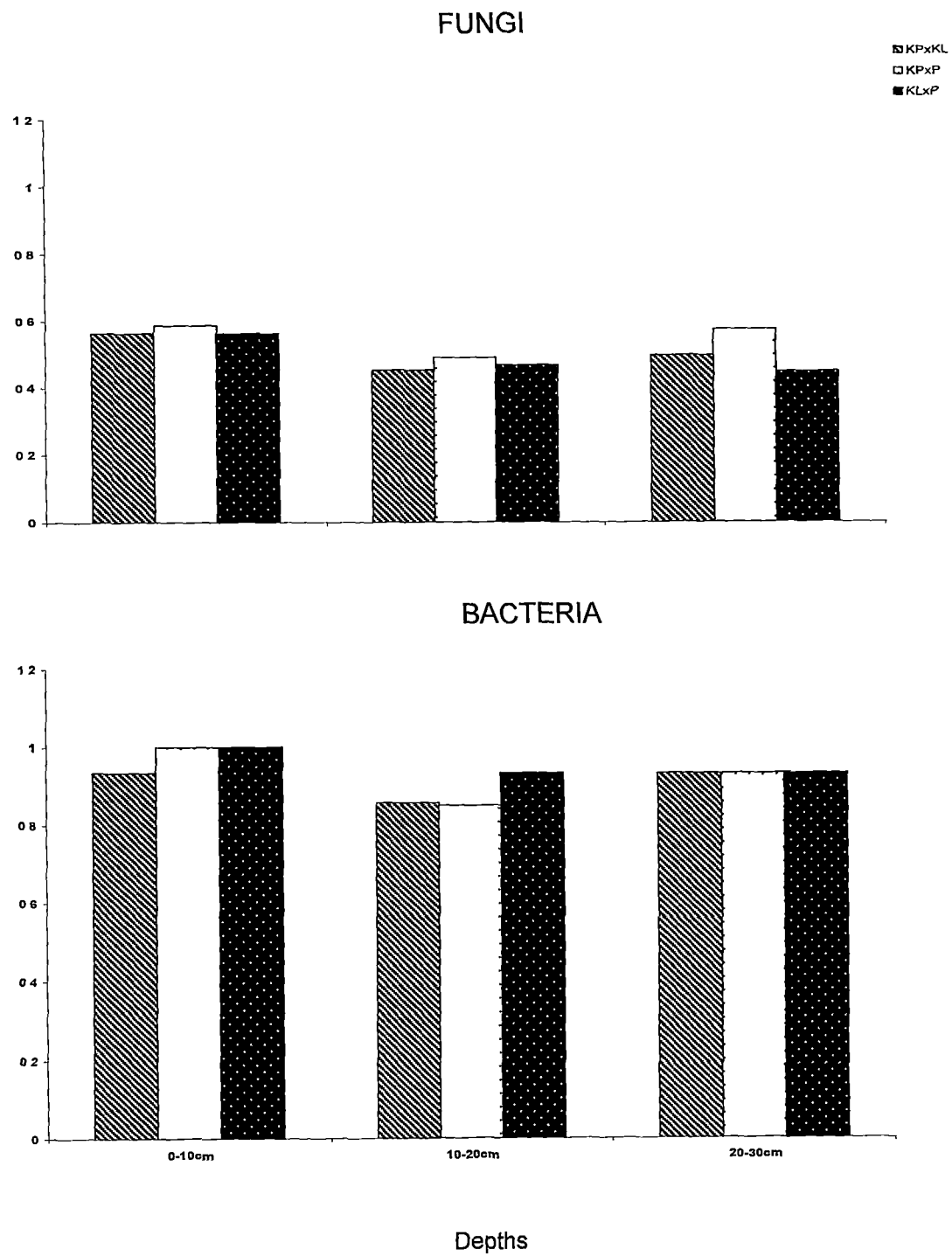


Fig 2 3 7 Sorensen similarity index of soil fungi and bacteria in two Sacred Groves and pine forest (2002 -2003)

Sl. No	Fungal species	STUDY SITES								
		KHLOO PAIUNG			KHLOO LANGDOH			PINE FOREST		
		0-10	10-20	20-30	0-10	10-20	20-20	0-10	10-20	20-30
22	<i>Chrysosporium panorum</i>	+	+	+	-	+	-	-	-	-
23	<i>Cylindrocarpon didymum</i>	-	-	-	-	+	-	-	-	-
24	<i>Eupenicillium brefeldianum</i>	-	-	+	+	-	-	+	+	+
25	<i>E. javanicum</i>	-	-	+	-	-	-	+	-	-
26	<i>Fusarium culmorum</i>	+	-	-	-	-	-	+	+	+
27	<i>F. oxysporum</i>	+	+	+	+	+	-	-	-	-
28	<i>F. poae</i>	-	-	-	-	-	-	+	+	+
29	<i>Gaeumannomyces graminis</i>	-	-	+	+	+	-	+	-	-
30	<i>Gliocladium catenulatum</i>	-	-	-	+	+	+	-	+	-
31	<i>G. roseum</i>	+	+	-	-	-	+	-	-	-
32	<i>Helminthosporium species</i>	+	+	-	+	-	-	-	-	-
33	<i>Humicola fuscoatra</i>	+	+	+	+	+	+	+	+	+
34	<i>H. grisea</i>	+	-	+	-	-	+	-	-	-
35	<i>Mamaria echinobotryoides</i>	-	-	+	+	-	-	-	-	-
36	<i>Mortierella bisporalis</i>	-	+	-	-	+	-	-	-	+
37	<i>M. hyalina</i>	-	-	+	-	-	+	-	+	-
38	<i>M. polycephala</i>	+	-	+	+	+	+		+	+
39	<i>Mucor circinelloides</i>	+	+	+	+	+	-	+	+	+
40	<i>M. hiemalis</i>	+	+	+	-	-	-	+	+	+
41	<i>M. racemosus</i>	-	-	-	+	-	-	+	+	+

Sl. No	Fungal species	STUDY SITES								
		KHLOO PAIUNG			KHLOO LANGDOH			PINE FOREST		
		0-10	10-20	20-30	0-10	10-20	20-20	0-10	10-20	20-30
42	<i>Nectria ventricosa</i>	-	+	-	+	-	+	-	+	-
43	<i>Oidiodendron echinulatum</i>	-	+	-	-	+	-	-	-	-
44	<i>O. griseum</i>	-	-	+	-	-	-	-	+	+
45	<i>O. rhodogenum</i>	-	-	-	+	-	+	-	-	-
46	<i>O. tenuissimum</i>	+	-	-	-	-	-	-	-	+
47	<i>O. truncatum</i>	+	+	+	-	-	-	-	+	-
48	<i>Paecilomyces cameus</i>	+	+	+	+	+	+	-	+	+
49	<i>Papula spora</i>	+	-	-	-	-	-	-	-	-
50	<i>Penicillium brevicompactum</i>	+	+	+	+	+	+	+	+	+
51	<i>P. canescens</i>	+	-	+	+	+	+	+	-	-
52	<i>P. chrysogenum</i>	-	+	-	-	-	-	+	+	+
53	<i>P. decumbens</i>	-	-	-	-	-	-	+	-	-
54	<i>P. frequentans</i>	+	+	+	+	+	+	+	-	-
55	<i>P. funiculosum</i>	+	-	+	+	+	+	-	+	-
56	<i>P. granulatum</i>	+	+	+	-	-	-	+	+	+
57	<i>P. janthinellum</i>	-	-	-	-	-	-	+	+	-
58	<i>P. herquiei</i>	-	-	-	+	+	+	-	-	-
59	<i>P. islandicum</i>	-	-	-	+	-	-	-	-	-
60	<i>P. jensenii</i>	+	+	+	+	+	+	-	+	+
61	<i>P. lanosum</i>	-	+	+	+	+	+	+	+	-

Sl. No	Fungal species	STUDY SITES								
		KHLOO PAIUNG			KHLOO LANGDOH			PINE FOREST		
		0-10	10-20	20-30	0-10	10-20	20-20	0-10	10-20	20-30
62	<i>P. levidum</i>	+	+	+	+	-	-	-	-	-
63	<i>P. nigrican</i>	+	+	+	+	+	+	-	-	-
64	<i>P. oxalicum</i>	-	-	-	-	-	-	-	-	+
65	<i>P. purpurogenum</i>	+	+	+	-	-	-	-	-	+
66	<i>P. restrictum</i>	-	-	-	+	-	+	+	-	-
67	<i>P. rubrum</i>	+	+	+	-	-	-	-	-	-
68	<i>P. sacculum</i>	-	-	+	+	+	+	-	-	-
69	<i>P. stoloniferum</i>	-	-	-	-	+	-	+	-	-
70	<i>P. waksmanii</i>	+	+	-	+	+	+	-	-	-
71	<i>Phoma eupyrrina</i>	-	+	-	+	+	+	-	-	-
72	<i>Phytophthora cactorum</i>	-	-	-	-	-	-	-	+	-
73	<i>Plectosphaerella cucumerina</i>	+	-	+	-	-	+	-	-	-
74	<i>Preussia fumiculata</i>	-	-	-	+	-	-	-	-	-
75	<i>Pythium intermedium</i>	+	-	-	+	+	+	+	+	+
76	<i>P. oligaridum</i>	-	+	+	+	-	-	-	-	-
77	<i>P. paroecandrum</i>	-	-	+	+	+	-	-	-	-
78	<i>Scopulariopsis brevicaulis</i>	-	+	-	-	-	-	-	-	-
79	<i>S. bruntii</i>	-	-	-	-	-	-	+	+	+
80	<i>Syncephalastrum racemosum</i>	-	-	-	+	+	+	+	+	+

Sl. No	Fungal species	STUDY SITES								
		KHLOO PAIUNG			KHLOO LANGDOH			PINE FOREST		
		0-10	10-20	20-30	0-10	10-20	20-20	0-10	10-20	20-30
81	<i>Trichoderma harzianum</i>	+	+	+	+	+	-	-	+	-
82	<i>T.hematum</i>	+	-	-	-	-	-	+	-	-
83	<i>T.koningii</i>	+	+	+	+	+	+	+	+	+
84	<i>T.species</i>	-	-	+	-	-	-	-	-	-
85	<i>T.virede</i>	+	+	+	+	+	+	+	+	+
86	<i>Verticillium alboatrum</i>	+	+	-	+	+	+	+	-	+
87	<i>V.chlamydosporium</i>	+	+	+	+	+	+	-	-	-
88	<i>V.lecanii</i>	-	+	+	-	+	-	-	-	-
89	<i>V.nigrescens</i>	+	+	-	-	-	-	+	-	-
90	<i>Zygorhynchus heterogamous</i>	+	+	-	-	-	-	-	-	-
91	<i>Sterile mycelium (yellow)</i>	+	+	+	+	+	+	+	-	-
92	<i>Sterile mycelium (orange)</i>	+	-	-	-	-	-	-	-	+
93	<i>Sterile mycelium (white)</i>	+	+	+	+	+	+	+	+	-
94	<i>Sterile mycelium (brown)</i>	-	+	-	+	-	-	+	+	+
95	<i>Sterile mycelium (green)</i>		-	+	-	-	+	-	-	-

Table 2.3.3. Bimonthly variation in the population of fungal species per gram dry soil X 10³ in Khloo Paiung soil at 0-10 cm depth (February 2002 - December 2003). Values in the parentheses are percentage relative abundance.

Sl No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
1	<i>Absidia corymbifera</i>	-	0.350 (4.444)	-	-	-	-	-	1.724 (10.869)	0.344 (3.70)	-	-	-
2	<i>Acremonium butyris</i>	-	0.526 (6.666)	-	-	-	-	-	2.068 (13.043)	1.551 (9.78)	-	-	-
3	<i>A.kiliense</i>	0.666 (16.17)	-	-	-	-	-	1.25 (32)	-	-	-	-	-
4	<i>A. murorum</i>	-	-	-	-	-	-	-	-	-	-	0.317 (4)	-
5	<i>Aspergillus alutaceus</i>	0.533 (12.903)	-	-	-	-	-	-	-	-	-	-	-
6	<i>A. carneus</i>	-	-	-	-	-	0.5 (10)	-	-	-	-	-	0.468 (10.714)
7	<i>A. flavus</i>	-	-	-	-	0.508 (8.571)	-	-	-	-	-	3.174 (40)	-
8	<i>A. fumigatus</i>	-	-	-	-	-	-	-	-	3.448 (37.037)	3.454 (30.454)	1.111 (14)	-
9	<i>A. niger</i>	-	-	-	0.727 (6.451)	-	-	-	-	-	0.727 (6.451)	-	-
10	<i>A. oryzae</i>	-	0.877 (11.111)	-	-	-	-	-	-	-	-	-	-
11	<i>Botryotrichum piluliferum</i>	-	-	0.983 (10)	-	-	-	-	-	-	-	-	-
12	<i>Broomella acuta</i>	-	-	0.655 (6.666)	-	-	-	-	-	-	-	0.476 (6)	-
13	<i>Cladosporium asperatum</i>	-	-	-	-	0.508 (8.571)	-	-	-	-	-	-	-
14	<i>C. cladosporoides</i>	0.4 (9.677)	-	-	-	-	0.333 (6.666)	-	4.137 (26.086)	-	-	0.158 (2)	0.625 (14.285)

SI No	Fungal species	F 02	A 02	J 02	A 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
15	<i>Chrysosporium panorum</i>	-	-	-	-	-	-	-	-	-	0.517 (5.55)	-	0.317 (4)	-
16	<i>Fusarium culmorum</i>	-	-	-	-	-	-	-	-	-	0.1 (5.55)	-	-	-
17	<i>F. oxysporum</i>	-	-	1.311 (13.333)	-	-	-	-	-	-	-	-	-	-
18	<i>G. roseum</i>	-	1.578 (20)	-	-	-	-	-	-	-	-	-	-	-
19	<i>Helminthosporium species</i>	-	-	0.983 (10)	-	-	-	-	-	-	-	-	-	-
20	<i>Humicola fuscoatra</i>	-	-	-	-	-	-	-	-	1.379 (8.695)	-	-	-	0.468 (10.714)
21	<i>H. grisea</i>	-	-	-	-	-	-	-	0.223 (5)	-	-	-	-	-
22	<i>Montierella polycephala</i>	-	-	-	-	-	0.388 (5.714)	-	-	-	-	-	0.634 (8)	-
23	<i>Mucor circinelloides</i>	0.533 (12.903)	-	-	-	-	-	-	-	-	-	-	-	-
24	<i>M. hiemalis</i>	0.8 (19.354)	-	-	-	-	-	-	-	-	-	-	-	-
25	<i>Oidiodendron echinulatum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-
26	<i>O. tenuissimum</i>	-	-	-	-	-	-	-	-	-	0.172 (2.17)	0.363 (3.225)	-	-
27	<i>O. truncatum</i>	0.266 (6.45)	-	-	-	-	-	-	-	-	-	-	-	-
28	<i>Papula spora</i>	0.4 (9.677)	-	-	-	-	-	-	-	-	-	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
29	<i>Paecilomyces carneus</i>	-	-	-	1.090 (14.285)	1.016 (17.14)	-	-	-	0.689 (7.40)	0.727 (1.61)	0.793 (10)	-
30	<i>Penicillium brevicompactum</i>	-	-	0.983 (10)	0.909 (11.904)	-	0.333 (6.666)	-	-	-	0.363 (3.222)	-	0.781 (17.857)
31	<i>P. canescens</i>	-	-	-	-	0.338 (5.704)	-	-	-	-	-	-	-
32	<i>P. frequentans</i>	-	-	-	1.09 (14.28)	-	-	-	1.206 (7.608)	-	-	-	--
33	<i>P. funiculosus</i>	-	-	-	-	0.338 (5.714)	0.833 (16.666)	-	-	0.689 (7.40)	-	-	0.625 (14.285)
34	<i>P. granulatum</i>	-	-	-	2 (26.19)	-	-	-	-	-	-	0.158 (2)	-
35	<i>P. jensenii</i>	-	-	-	1.454 (19.04)	-	-	-	0.517 (3.26)	0.172 (1.85)	-	-	-
36	<i>P. levidum</i>	-	-	-	-	-	-	0.781 (20)	-	-	-	-	-
37	<i>P. nigricans</i>	-	1.052 (13.333)	1.475 (15)	-	-	-	-	-	-	-	-	-
38	<i>P. purpurogenum</i>	0.266 (6.45)	-	-	-	-	0.333 (6.666)	-	-	-	-	-	-
39	<i>P. rubrum</i>	-	-	-	-	0.677 (11.428)	-	-	-	-	4.36 (38.709)	-	-
40	<i>P. waksmanii</i>	-	-	-	-	-	-	-	-	-	-	-	0.781 (17.857)
41	<i>Plectosphaerella cucumerina</i>	-	-	-	-	-	-	0.625 (16)	-	-	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
42	<i>Pythium intermedium</i>	-	-	1.475 (15)	-	-	1.5 (30)	-	-	-	-	-	-
43	<i>Trichoderma koningii</i>	-	-	1.639 (16.666)	1.636 (7.31)	1.016 (17.14)	0.5 (10)	-	-	1.896 (20.37)	0.727 (6.46)	0.476 (6)	0.312 (7.142)
44	<i>T. harzianum</i>	-	1.228 (15.555)	-	-	0.338 (5.714)	0.5 (10)	-	-	-	-	-	-
45	<i>T. hamatum</i>	0.266 (6.45)	-	-	-	-	-	0.447 (10)	-	-	-	-	-
46	<i>T. viride</i>	-	-	-	-	0.677 (11.428)	-	-	1.206 (7.608)	-	-	-	-
47	<i>Verticillium albo-atrum</i>	-	-	-	-	0.338 (5.714)	-	-	1.379 (8.695)	-	-	-	-
48	<i>V. chlamydosporium</i>	-	1.929 (24.44)	-	-	-	-	-	-	-	1.09 (9.67)	-	-
49	<i>V. nigriscens</i>	-	-	-	-	-	-	-	-	-	-	-	-
50	<i>Zygorhynchus heterogamus</i>	-	-	-	-	-	-	0.781 (20)	-	-	-	-	-
51	<i>White sterile mycelia</i>	-	0.350 (4.444)	0.655 (6.666)	0.545 (7.142)	-	0.166 (3.84)	-	0.517 (3.26)	-	-	-	0.468 (10.714)
52	<i>Orange sterile mycelia</i>	-	-	-	-	-	-	-	1.724 (10.869)	-	-	-	-
52	<i>Yellow sterile mycelia</i>	-	-	-	-	-	-	-	-	-	-	0.317 (4)	-

Table 2.3.4. Bimonthly variation in the population of fungal species per gram dry soil X 10³ in Khloo Paiung soil at 10-20 cm depth (February 2002- December 2003). Values in the parentheses are percentage relative abundance.

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
1	<i>Absidia cylindrospora</i>	-	-	-	-	-	-	1.044 (11.66)	-	-	3.508 (35)	-	-
2	<i>A. corymbifera</i>	-	-	-	-	-	-	-	1.034 (11.53)	-	-	0.303 (3.636)	-
3	<i>Alternaria tenuissima</i>	0.52 (13.793)	-	-	-	-	-	-	0.344 (3.84)	-	-	-	-
4	<i>Aspergillus. carneus</i>	-	-	-	-	-	0.152 (3.184)	-	-	-	-	-	0.606 (17.391)
5	<i>A. flavus</i>	-	-	-	0.483 (9.09)	0.322 (13.3)	-	-	-	-	-	1.06 (20.93)	-
6	<i>A. fumigatus</i>	-	0.508 (8.333)	0.0.781 (11.627)	-	-	-	-	-	1.803 (36.666)	-	-	-
7	<i>A. niger</i>	-	-	-	-	-	-	0.597 (6.666)	0.517 (5.76)	-	-	-	-
8	<i>A. oryzae</i>	-	0.677 (11.111)	-	-	-	-	-	-	-	-	-	-
9	<i>Cladosporium asperatum</i>	-	-	-	-	-	-	0.597 (6.666)	-	-	-	-	-
10	<i>C. cladosporoides</i>	-	-	-	-	-	-	0.895 (10)	2.24 (26.92)	-	-	-	-
11	<i>Chrysosporium panorum</i>	-	-	0.625 (9.302)	-	0.645 (33.333)	0.156 (3.184)	-	-	0.517 (5.555)	-	-	-
12	<i>Fusarium oxysporum</i>	-	-	0.781 (11.627)	-	-	-	-	-	-	-	0.454 (5.454)	-
13	<i>Gladiolium roseum</i>	-	-	-	-	-	-	-	1.379 (15.38)	-	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
14	<i>Helminthosporium species</i>	-	-	0.625 (9.302)	-	-	-	-	-	-	-	-	-
15	<i>Humicola fuscoatra</i>	-	-	-	-	-	-	-	0.689 (9.61)	-	-	0.634 (9.09)	-
16	<i>Mortierella polycephala</i>	-	-	-	-	-	-	0.289 (4.545)	-	-	-	-	-
17	<i>Mucor circinelloides</i>	0.52 (13.793)	-	-	-	-	-	-	-	-	-	-	0.757 (21.739)
18	<i>M. hiemalis</i>	0.657 (17.241)	-	-	-	-	-	0.781 (6.66)	-	-	-	-	-
19	<i>Nectria ventricosa</i>	-	-	-	-	-	-	-	0.344 (3.84)	-	-	-	-
20	<i>Oidiodendron echinulatum</i>	-	-	-	-	-	-	-	-	1.551 (16.666)	-	-	-
21	<i>O. truncatum</i>	-	-	-	-	-	-	-	-	-	0.526 (7.5)	-	-
22	<i>Paecilomyces carneus</i>	-	-	0.468 (6.976)-	0.483 (9.09)	0.161 (6.66)	-	-	-	-	0.701 (10)	0.606 (7.272)	-
23	<i>Penicillium brevicompactum</i>	-	-	0.468 (6.976)	0.645 (12.121)	-	-	-	-	-	0.175 (2.5)	0.757 (9.09)	-
24	<i>P. chrysogenum</i>	-	-	-	0.322 (6.06)	-	-	-	-	-	-	-	-
25	<i>P. frequentans</i>	-	-	-	0.645 (12.121)	-	-	-	-	1.034 (11.111)	-	-	-
26	<i>P. granulatum</i>	-	-	-	1.147 (30.303)	-	-	-	-	-	-	-	-
27	<i>P. funiculosum</i>	-	-	0.781 (11.627)	-	-	0.625 (15.38)	-	-	-	-	1.363 (16.363)	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
28	<i>P. jensenii</i>	-	-	0.468 (6.976)	-	-	-	-	-	-	-	-	-
29	<i>P. lanosum</i>	-	-	-	-	-	-	-	0.344 (3.84)	-	-	-	-
30	<i>P. levidum</i>	0.789 (20.689)	-	-	-	-	-	1.194 (13.33)	-	-	-	-	-
31	<i>P. nigricans</i>	-	0.677 (11.111)	0.937 (13.953)	-	-	-	-	0.344 (3.84)	-	-	-	-
32	<i>P. purpurogenum</i>	-	-	-	-	-	0.468 (11.53)	-	-	-	-	-	-
33	<i>P. rubrum</i>	-	-	-	-	0.483 (25)	-	-	-	-	0.877 (12.2)	-	-
34	<i>P. waksmanii</i>	-	-	0.468 (6.976)	-	-	0.781 (19.23)	-	-	0.689 (7.407)	-	-	0.454 (13.043)
35	<i>Phoma eupyrrina</i>	-	-	-	-	-	-	0.597 (6.66)	-	-	-	-	-
36	<i>P. oligaridum</i>	-	-	0.313 (4.651)	-	-	0.625 (15.38)	-	-	-	-	-	0.909 (26.086)
37	<i>Scopulariopsis brevicaulis</i>	-	-	-	-	-	-	0.597 (6.66)	-	-	-	-	-
38	<i>Trichoderma koningii</i>	0.657 (17.241)	-	0.468 (6.976)	0.806 (15.151)	0.322 (13.3)	0.468 (11.538)	-	-	0.689 (7.407)	-	1.363 (16.363)	0.303 (8.695)
39	<i>T. harzianum</i>	-	0.847 (13.888)	-	-	-	0.625 (15.834)	1.79 (20)	-	-	0.757 (9.09)	-	-
40	<i>T. veride</i>	-	0.677 (11.111)	-	-	-	-	-	0.862 (9.61)	-	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
41	<i>Verticillium alboatrum</i>	-	-	-	-	0.161 (6.66)	-	-	-	0.862 (9.259)	-	-	-
42	<i>V. chlamydosporium</i>	-	-	-	1.525 (25)	-	-	-	-	-	-	-	-
43	<i>V. lecanii</i>	-	-	-	-	-	-	-	-	-	-	0.454 (5.454)	-
44	<i>V. nigrescens</i>	-	-	-	1.186 (19.444)	-	-	-	-	-	-	-	-
45	<i>Zygorrhynchus heterogamus</i>	-	-	-	-	-	-	0.781 (6.66)	-	-	-	-	-
46	<i>White sterile mycelia</i>	-	-	-	0.338 (5.555)	-	0.156 (3.846)	-	0.344 (3.84)	-	0.35 (5)	0.303 (3.636)	0.454 (13.043)
47	<i>Brown sterile mycelia</i>	-	-	-	-	-	-	-	-	0.172 (1.851)	0.175 (10)	-	-
48	<i>Yellow sterile mycelia</i>	0.657 (17.241)	-	-	-	-	-	-	-	0.344 (3.703)	0.757 (9.09)	-	-

Table 2.3.5. Bimonthly variation in the population of fungal species per gram dry soil X 10³ in Khloo Paiung soil at 20-30 cm depth (February 2002- December 2003). Values in the parentheses are percentage relative abundance.

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
1	<i>Absidia cylindrospora</i>	-	-	-	-	-	-	-	-	-	1.739 (34.285)	-	-
2	<i>A. corymbifera</i>	-	-	-	-	-	-	-	-	0.161 (3.03)	-	-	-
3	<i>Aspergillus candidus</i>	-	-	-	-	-	-	-	0.819 (12.90)	-	-	-	-
4	<i>A. carneus</i>	-	-	-	-	-	1.09 (33.33)	-	-	-	-	-	0.606 (15)
5	<i>A. flavus</i>	-	-	-	-	-	-	0.322 (16.66)	-	-	-	1.06 (20.93)	-
6	<i>A. fumigatus</i>	-	0.833 (15.151)	0.714 (13.888)	-	-	-	-	-	0.967 (18.18)	1.449 (28.57)	1.594 (25.581)	-
7	<i>Cladosporium asperatum</i>	-	-	0.571 (11.111)	-	-	-	-	-	-	-	-	-
8	<i>C. cladosporoides</i>	-	-	-	-	-	0.147 (4.54)	1 (16.66)	1.311 (25.806)	0.483 (9.09)	-	-	-
9	<i>Chrysosporium panorum</i>	-	-	-	-	-	-	-	-	0.322 (6.06)	-	-	-
10	<i>Eupenicillium brefeldianum</i>	-	-	-	-	-	-	-	0.327 (6.451)	-	-	-	-
11	<i>E. javanicum</i>	-	-	-	-	-	-	-	-	0.483 (9.09)	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
12	<i>Fusarium. oxysporum</i>	-						0.285 (4.74)	-	0.161 (3.03)	-	-	-
13	<i>Gaeumannomyces graminis</i>	-	-	-	-	-	-	-	-	-	-	0.724 (11.627)	-
14	<i>Humicola fuscoatra</i>	0.657 (18.518)	-	-	-	-	-	-	0.491 (9.67)	-	-	-	-
15	<i>H. grisea</i>	-	-	-	-	-	-	-	0.163 (3.225)	-	-	-	-
16	<i>Mamaria echinobotryoides</i>	-	-	-	-	-	-	-	-	0.483 (9.09)	-	-	-
17	<i>Mortierella hyalina</i>	-	-	0.714 (13.888)	-	-	-	-	-	-	-	-	-
18	<i>M. polycephala</i>	-	-	-	-	0.312 (15.384)	-	-	-	-	-	-	-
19	<i>Mucor circinelloides</i>	-	-	-	-	-	0.147 (4.54)	-	-	-	-	-	0.735 (25)
20	<i>M. hiemalis</i>	0.394 (11.111)	-	-	-	-	-	-	-	-	-	-	-
21	<i>Oidiodendron griseum</i>	-	-	0.571 (11.111)	-	-	-	-	-	-	-	-	-
22	<i>O. truncatum</i>	-	-	-	-	-	-	-	0.163 (3.22)	-	-	-	-
23	<i>Paecilomyces carneus</i>	-	-	-	-	0.491 (11.111)	0.156 (7.69)	-	-	-	-	0.434 (6.976)	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
24	<i>Penicillium brevicompactum</i>	-	-	-	0.491 (11.111)	0.156 (7.69)	0.454 (25)	-	-	-	-	0.724 (11.62)	0.588 (20)
25	<i>P. canescens</i>	0.921 (25.925)	-	-	-	0.312 (15.384)	-	-	-	-	-	-	-
26	<i>P. frequentans</i>	-	-	-	0.655 (14.814)	-	0.454 (25)	0.571 (9.52)	0.327 (6.451)	-	-	-	-
27	<i>P. funiculosum</i>	-	-	-	-	-	0.284 (9.09)	-	0.327 (6.451)	-	-	-	0.291 (10)
28	<i>P. granulatum</i>	-	-	-	1.147 (25.295)	-	-	-	-	-	-	-	-
29	<i>P. jensenii</i>	-	-	-	-	-	-	0.285 (4.76)	0.327 (6.451)	-	-	-	-
30	<i>P. lanosum</i>	-	-	-	-	-	-	1.571 (26.19)	-	-	-	-	-
31	<i>P. levidum</i>	0.526 (14.814)	-	-	-	-	-	-	-	-	-	-	-
32	<i>P. nigricans</i>	-	1 (18.18)	-	-	-	-	-	-	-	-	-	-
33	<i>P. purpurogenum</i>	-	-	0.483 (9.09)	-	-	-	-	-	0.645 (12.12)	-	-	-
34	<i>P. rubrum</i>	-	-	-	-	0.312 (15.384)	-	-	-	-	0.579 (11.42)	-	-
35	<i>P. sacculum</i>	-	-	-	-	-	-	0.285 (4.76)	-	-	-	-	-
36	<i>Plectosphaerella cucumerina</i>	-	-	0.571 (6.06)	-	-	-	-	-	0.322 (6.06)	-	-	-
37	<i>Pythium oligaridum</i>	-	-	0.428 (8.33)	-	-	-	-	-	-	-	-	0.882 (30)

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
38	<i>P. paroecandrum</i>	-	-	0.571 (11.111)	-	-	-	-	-	0.483 (9.09)	-	-	-
39	<i>Trichoderma koningii</i>	-	-	0.857 (16.666)	0.327 (7.407)	0.468 (23.076)	-	0.714 (11.90)	0.819 (12.90)	0.322 (6.06)	-	11.162 (17.141)	-
40	<i>T. harzianum</i>	-	1.5 (27.27)	-	-	-	-	-	-	-	-	-	-
41	<i>T. veride</i>	-	0.5 (9.09)	-	-	-	-	-	-	-	-	-	-
42	<i>T. species</i>	-	-	-	-	-	-	0.42 (7.14)	-	-	-	-	-
43	<i>Varicillium chlamydosporium</i>	-	1.333 (24.242)	-	-	-	-	-	-	-	-	-	-
44	<i>V. lecanii</i>	-	-	-	-	-	-	-	-	-	0.724 (14.28)	-	-
45	<i>White sterile mycelia</i>	1.05 (29.629)	0.333 (6.06)	-	-	-	-	0.285 (4.76)	-	0.483 (9.09)	0.434 (8.57)	-	-
46	<i>Green sterile mycelia</i>	-	-	-	-	-	-	0.285 (4.76)	0.163 (3.22)	-	-	-	-
47	<i>Yellow sterile mycelia</i>	-	-	-	-	-	-	-	0.163 (3.22)	-	0.144 (2.857)	0.289 (4.651)	-

Table 2.3.6. Bimonthly variation in the population of fungal species per gram dry soil X 10³ in Khloo Langdoh soil at 0-10 cm depth (February 2002- December 2003). Values in the parentheses are percentage relative abundance.

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
1	<i>Absidia cylindrospora</i>	-	-	-	-	-	-	-	-	0.312 (4.76)	0.149 (2.38)	0.597 (7.407)	-
2	<i>A. conymbifera</i>	0.493 (10)	-	-	-	-	-	-	0.634 (4.68)	0.312 (4.76)	-	-	-
3	<i>Aspergillus flavus</i>	0.493 (10)	0.694 (11.904)	0.441 (8.333)	-	-	-	0.322 (3.125)	-	-	-	-	-
4	<i>A. fumigatus</i>	-	-	-	-	-	-	-	-	0.312 (4.76)	1.044 (16.66)	-	-
5	<i>Cladosporium cladosporoides</i>	-	-	-	0.909 (14.634)	-	-	4.516 (43.75)	-	0.312 (4.76)	-	-	-
6	<i>Eupenicillium brefeldianum</i>	-	-	-	-	-	-	-	-	-	-	0.746 (9.259)	-
7	<i>Fusarium oxysporum</i>	-	-	-	-	-	-	-	-	-	0.298 (4.761)	-	-
8	<i>Gaeumannomyces graminis</i>	-	-	-	-	0.468 (4.76)	0.588 (8.333)	-	-	-	-	-	0.4 (8.823)
9	<i>Gladiolium catenulatum</i>	-	-	-	-	-	-	-	-	-	-	0.597 (7.407)	-
10	<i>Helminthosporium species</i>	0.37 (7.5)	-	-	-	-	-	-	-	-	-	-	-
11	<i>Humicola fuscoatra</i>	0.617 (12.5)	-	-	-	-	-	-	-	-	-	-	-
12	<i>Mamaria echinobotryoides</i>	-	-	-	-	-	-	-	-	-	-	0.298 (3.703)	-
13	<i>Mortierella polycephala</i>	-	-	-	-	-	0.294 (4.16)	0.322 (4.16)	-	-	-	0.298 (3.704)	0.533 (11.764)

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
14	<i>Mucor circinelloides</i>	-	-	-	-	-	-	0.322 (3.125)	-	-	-	-	-
15	<i>M. racemosus</i>	-	0.555 (9.523)	-	-	-	-	0.322 (3.125)	-	-	0.298 (4.761)	-	-
16	<i>Nectria ventricosa</i>	-	-	-	-	-	-	-	0.317 (3.125)	-	0.447 (7.14)	-	-
17	<i>Oidiodendron rhodogenum</i>	-	-	-	-	-	-	0.322 (3.125)	-	-	-	-	-
18	<i>Paecilomyces cameus</i>	0.370 (7.5)	-	-	-	-	-	0.645 (6.25)	-	-	-	-	-
19	<i>Penicillium brevicompactum</i>	0.493 (10)	-	0.882 (16.666)	-	-	0.166 (2.08)	0.483 (4.68)	-	0.468 (7.142)	-	0.597 (7.407)	-
20	<i>P. canescens</i>	-	0.972 (16.66 6)	-	0.909 (14.634)	-	-	-	-	-	0.447 (7.14)	0.447 (5.555)	-
21	<i>P. frequentans</i>	-	0.277 (4.761)	-	-	-	0.147 (2.08)	-	0.793 (7.81)	-	-	-	0.4 (8.823)
22	<i>P. funiculosum</i>	-	-	-	1.515 (24.39)	-	0.147 (2.08)	-	-	0.625 (9.523)	-	-	-
23	<i>P. herquei</i>	-	-	0.294 (5.555)	-	-	-	-	-	-	-	-	-
24	<i>P. islandicum</i>	-	-	-	0.303 (4.878)	-	-	-	-	-	-	-	-
25	<i>P. jensenii</i>	0.987 (20)	-	-	0.454 (7.317)	-	0.441 (6.25)	0.322 (3.12)	-	-	-	-	0.26 (5.882)
26	<i>P. lanosum</i>	0.246 (5)	-	0.588 (11.111)	-	0.468 (7.14)	-	-	-	-	-	-	-
27	<i>P. levidum</i>	-	-	-	-	1.093 (16.666)	-	-	-	-	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
28	<i>P. nigricans</i>	-	-	0.441 (8.333)	-	-	-	-	-	-	-	0.447 (5.555)	-
29	<i>P. restrictum</i>	-	-	-	1.363 (21.951)	-	-	-	-	-	-	-	-
30	<i>P. sacculum</i>	0.370 (7.5)	-	-	-	-	-	-	-	-	-	-	-
31	<i>P. waksmanii</i>	-	0.555 (9.523)	-	-	1.718 (26.19)	-	-	5.396 (53.125)	-	0.597 (9.52)	-	0.447 (5.555)
32	<i>Phoma eupyrena</i>	-	-	0.441 (8.333)	-	0.468 (7.14)	0.588 (9.523)	-	-	-	-	-	-
33	<i>Preussia fumiculata</i>	-	-	0.441 (8.333)	-	-	-	-	-	-	-	-	-
33	<i>Pythium intermedium</i>	-	-	0.441 (8.333)	-	0.468 (7.14)	0.441 (6.25)	-	0.476 (4.867)	0.468 (7.142)	-	-	-
34	<i>P. oligaridum</i>	-	-	-	-	-	-	1.451 (14.06)	-	-	-	-	0.26 (5.882)
35	<i>P. parocandrum</i>	-	-	-	-	-	-	-	-	-	0.833 (11.904)	-	-
36	<i>Syncephalastrum racemosum</i>	-	-	-	-	-	-	-	-	-	-	-	0.533 (11.764)
37	<i>Trichoderma koningii</i>	0.74 (15)	0.833 (14.285)	0.441 (8.333)	0.454 (7.31)	1.093 (16.66)	1.470 (20.333)	0.322 (3.125)	-	2.187 (33.333)	1.194 (19.407)	1.492 (18.518)	0.666 (14.705)
38	<i>T. harzianum</i>	-	-	-	0.303 (4.87)	-	-	-	-	-	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
39	<i>T. veride</i>	0.246 (5)	-	0.441 (8.333)	-	0.468 (4.76)	0.441 (6.25)	-	-	-	-	-	-
40	<i>Verticillium alboatrum</i>	-	-	-	-	-	0.735 (10.416)	0.645 (6.25)	-	-	-	-	0.933 (20.588)
41	<i>V. chlamydosporium</i>	-	-	0.294 (5.555)	-	-	0.882 (12.5)	-	-	-	-	-	-
42	<i>White sterile mycelia</i>	-	0.138 (2.38)	-	0.454 (7.317)	0.625 (9.52)	0.588 (8.333)	-	-	-	0.298 (14.285)	0.447 (4.76)	0.26 (5.555)
43	<i>Brown sterile mycelia</i>	-	-	0.294 (5.555)	-	-	-	-	-	-	-	-	-
44	<i>Yellow sterile mycelia</i>	-	-	-	-	-	0.147 (2.08)	-	-	-	-	-	0.4 (8.823)

Table 2.3.7. Bimonthly variation in the population of fungal species per gram dry soil X 10³ in Khloo Langdoh soil at 10-20cm depth (February -2002- December – 2003). The value in the parentheses is the relative abundance.

Sl no	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A 03	J 03	A 03	O 03	D 03
1	<i>Absidia cylindrospora</i>	-	-	0.294 (6.666)	-	-	-	-	-	-	-	-	-
2	<i>A. corymbifera</i>	-	-	0.441 (10)	-	-	-	-	0.454 (4.91)	-	-	-	-
3	<i>Acremonium butyris</i>	-	-	-	-	-	-	-	-	-	0.156 (3.33)	-	-
4	<i>A. murorum</i>	-	-	-	-	-	-	0.303 (2.27)	0.606 (6.56)	-	-	-	-
5	<i>Alternaria altinata</i>	-	-	-	-	-	-	-	0.303 (3.27)	-	-	-	-
6	<i>Aspergillus alutaceus</i>	-	0.410 (11.538)	-	-	-	0.882 (5)	-	-	-	-	-	0.657 (17.857)
7	<i>A. candidus</i>	-	-	-	-	-	-	-	-	-	0.156	-	-
8	<i>A. carneus</i>	0.487 (12.121)	-	-	-	-	-	-	-	-	-	-	-
9	<i>A. flavus</i>	-	-	-	-	-	-	-	-	-	-	0.657 (10.204)	-
10	<i>A. fumigatus</i>	0.365 (9.09)	-	0.441 (10)	-	-	-	-	-	0.144 (3.57)	-	0.526 (8.163)	-
11	<i>Cladosporium cladosporioides</i>	-	-	-	-	-	-	1.515 (15.90)	0.909 (25)	-	-	-	-
12	<i>Chrysosporium panorum</i>	-	-	0.441 (10)	-	-	-	-	-	-	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
13	<i>Cylindrocarpon didymum</i>	-	-	-	-	-	-	0.606 (9.09)	-	-	-	-	-
14	<i>Fusarium oxysporum</i>	-	-	-	-	-	-	0.757 (11.36)	-	-	-	-	-
15	<i>Gaeumannomyces graminis</i>	-	-	-	-	-	-	-	-	-	-	-	0.526 (14.285)
16	<i>Gliocladium catenulatum</i>	-	-	-	-	-	-	-	-	-	1.406 (30)	-	-
17	<i>Humicola fuscoatra</i>	-	-	-	-	-	-	-	0.454 (4.918)	-	-	-	-
18	<i>Mortierella bisporalis</i>	0.243 (6.06)	-	-	-	-	-	-	-	0.144 (3.57)	-	-	-
19	<i>M. polycephala</i>	0.487 (12.121)	-	-	-	-	-	0.303 (4.545)	-	-	-	0.394 (6.122)	0.657 (17.857)
20	<i>Mucor circinelloides</i>	-	0.273 (7.692)	-	-	-	-	-	-	-	-	-	-
21	<i>Oidiodendron echinulatum</i>	-	-	-	-	-	-	-	-	-	-	0.526 (8.163)	-
22	<i>Paecilomyces cameus</i>	-	-	-	-	-	-	-	0.606 (6.55)	-	-	-	-
23	<i>Penicillium brevicompactum</i>	0.365 (9.09)	0.547 (15.384)	0.588 (13.333)	-	-	-	0.454 (6.81)	0.303 (3.27)	0.666 (14.28)	0.463 (10)	-	-
24	<i>P. canescens</i>	-	0.684 (19.23)	-	-	-	-	-	-	-	-	-	-
25	<i>P. frequentans</i>	0.731 (18.181)	-	-	-	-	-	-	0.909 (9.83)	-	0.312 (6.666)	0.263 (4.081)	-
26	<i>P. funiculosum</i>	-	-	-	0.416 (14.285)	-	-	-	-	-	-	1.052 (16.326)	-
27	<i>P. herquiei</i>	-	-	0.735 (16.666)	-	-	-	-	-	0.289 (10.71)	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
28	<i>P. jensenii</i>	0.609 (15.151)	-	-	0.277 (9.523)	-	0.588 (20)	0.454 (6.818)	-	-	-	-	-
29	<i>P. lanosum</i>	0.243 (6.06)	-	-	-	-	-	0.454 (6.818)	0.454 (4.91)	0.289 (7.14)	-	0.394 (6.122)	-
30	<i>P. nigrans</i>	-	-	-	0.416 (14.285)	-	-	0.303 (4.54)	-	-	-	0.789 (12.244)	-
31	<i>P. sacculum</i>	-	-	-	-	-	-	-	-	-	-	0.263 (4.081)	-
32	<i>P. stoloniferum</i>	-	-	-	-	-	-	-	-	-	-	0.263 (4.081)	-
33	<i>P. waksmanii</i>	-	0.410 (11.538)	-	-	1.212 (38.095)	-	-	3.636 (39.344)	-	-	0.526 (8.163)	-
34	<i>Phoma eupyria</i>	-	-	-	-	-	0.294 (10)	-	-	-	-	-	-
35	<i>Pythium intermedium</i>	-	-	0.441 (10)	0.555 (19.047)	0.454 (14.28)	-	-	-	-	-	-	-
36	<i>P. parocandrum</i>	-	0.547 (15.384)	-	-	-	-	-	-	-	-	-	-
37	<i>Syncephalastrum racemosum</i>	-	-	-	-	-	-	-	-	-	-	0.526 (8.163)	-
38	<i>Trichoderma koningii</i>	0.243 (6.06)	0.684 (19.23)	0.441 (10)	0.416 (14.285)	-	-	0.454 (6.818)	0.606 (6.557)	1.014 (25)	0.312 (6.666)	0.526 (8.763)	0.526 (14.285)

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
39	<i>T. harzianum</i>	-	-	-	-	0.454 (14.285)	-	-	-	0.434 (10.71)	-	-	-
40	<i>T. veride</i>	-	-	0.294 (6.666)	-	0.303 (9.523)	0.441 (20)	-	-	-	-	-	-
41	<i>Verticillium alboatrum</i>	0.243 (6.06)	-	-	-	-	0.735 (25)	-	-	0.724 (17.85)	-	-	0.657 (17.857)
42	<i>V. chlamydosporium</i>	-	-	-	-	-	0.882 (5)	-	-	-	1.406 (36)	0.263 (4.081)	-
43	<i>V. lecanii</i>	-	-	-	-	0.606 (19.047)	-	-	-	-	-	-	-
44	<i>White sterile mycelia</i>	-	-	0.294 (6.666)	-	0.454 (14.285)	0.147 (5)	0.303 (4.54)	-	0.289 (7.14)	0.312 (6.66)	0.526 (8.763)	0.394 (10.714)
45	<i>Yellow sterile mycelia</i>	-	-	-	-	-	0.294 (10)	0.303 (4.54)	-	-	-	-	0.263 (7.142)

Table 2.3.8. Bimonthly variation in the population of fungal species per gram dry soil X 10³ in Khloo Langdoh soil at 20- 30 cm depth (February- 2002 -December-2003). The value in the parentheses is the relative abundance.

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
1	<i>Absidia corymbifera</i>	-	0.405 (12.5)	-	-	-	-	-	-	-	-	-	-
2	<i>Acremonium butyrinis</i>	-	0.405 (12.5)	-	-	-	-	-	-	-	0.461 (12)	-	-
3	<i>A. kilense</i>	-	-	-	-	-	-	-	-	-	0.615 (16)	-	-
4	<i>A. strictum</i>	-	-	-	-	-	-	1.19 (16.32)	-	-	-	-	-
5	<i>Aspergillus alutaceus</i>	-	-	-	-	-	-	-	-	-	-	-	0.526 (11.764)
6	<i>A. carneus</i>	0.232 (8.333)	-	-	-	-	-	-	-	-	-	-	-
7	<i>A. flavus</i>	-	-	-	-	-	-	-	-	-	-	1.025 (20.512)	-
8	<i>A. fumigatus</i>	-	-	-	-	-	-	-	-	0.746 (16.12)	-	1.315 (20.512)	-
9	<i>A. oryzae</i>	-	-	0.735 (16.666)	-	-	-	-	-	-	-	-	-
10	<i>Botryotrichum piluliferum</i>	-	-	0.441 (10)	-	-	-	-	-	-	-	0.657 (12.82)	0.657 (14.705)
11	<i>Cladosporium cladosporoides</i>	-	-	-	-	-	-	0.895 (12.24)	1.492 (16.94)	0.447 (9.67)	-	-	-
12	<i>Gliocladium catenulatum</i>	-	-	-	-	-	-	-	-	-	0.461 (12)	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
13	<i>G. roseum</i>	-	-	-	-	-	-	-	0.746 (8.47)	-	-	-	-
14	<i>Humicola fuscoatra</i>	-	-	-	-	-	-	-	-	-	0.461 (12)	-	-
15	<i>H. grisea</i>	-	-	-	-	-	-	0.447 (6.16)	-	-	-	-	-
16	<i>M. hyalina</i>	-	-	-	-	-	-	0.298 (2.04)	-	-	-	-	-
17	<i>M. polycephala</i>	0.582 (20.833)	-	-	-	-	-	-	-	-	-	-	-
18	<i>Nectria ventricosa</i>	-	-	-	-	-	-	-	-	-	0.307 (8)	-	-
19	<i>Oidiodendron rhodogenum</i>	0.697 (25)	-	-	-	-	0.588 (26.666)	-	-	-	-	-	-
20	<i>Paecilomyces cameus</i>	-	-	-	-	-	-	0.289 (4.08)	0.746 (8.47)	-	-	-	-
21	<i>Penicillium brevicompactum</i>	0.348 (12.5)	0.540 (16.666)	0.441 (10)	0.394 (20)	-	-	0.447 (6.122)	0.298 (3.38)	-	-	-	-
22	<i>P. canescens</i>	-	0.675 (20.833)	-	-	-	-	-	-	-	0.307 (8)	-	-
23	<i>P. frequentans</i>	-	0.270 (8.333)	-	-	-	-	-	-	-	-	-	0.789 (17.647)
24	<i>P. funiculosum</i>	-	-	1.176 (26.666)	0.526 (26.666)	0.441 (16.66)	-	-	-	0.597 (12.903)	-	-	-
25	<i>P. herquiei</i>	-	-	-	0.394 (20)	-	-	-	-	-	-	-	-
26	<i>P. jensenii</i>	0.465 (16.666)	-	-	-	0.588 (26.66)	0.882 (40)	-	-	0.746 (16.12)	-	-	0.263 (5.882)

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
27	<i>P. lanosum</i>	-	0.675 (20.833)	-	-	-	-	0.597 (8.16)	-	-	-	-	-
28	<i>P. nigricans</i>	-	-	-	-	0.294 (9.523)	-	-	-	-	-	0.789 (15.384)	-
29	<i>P. restrictum</i>	-	-	0.588 (13.333)	-	-	-	0.597 (8.16)	-	-	-	-	-
30	<i>P. sacculum</i>	-	-	-	-	-	-	-	5.223 (59.32)	-	-	-	-
31	<i>P. waksmanii</i>	-	-	-	-	0.735 (23.809)	-	0.447 (6.122)	-	-	-	-	-
32	<i>Plectosphaerella cucumerina</i>	-	-	-	-	-	-	-	-	-	-	-	-
33	<i>Phoma eupyrrina</i>	-	-	0.294 (6.666)	-	-	0.294 (13.333)	-	-	-	-	-	-
34	<i>Pythium intermedium</i>	-	-	0.294 (6.666)	0.394 (20)	-	-	0.298 (4.08)	0.298 (3.38)	-	-	-	-
35	<i>Syncephalastrum racemosum</i>	-	-	-	-	-	-	-	-	-	-	0.526 (10.256)	-
36	<i>Trichoderma koningii</i>	0.232 (8.333)	-	0.441 (10)	-	0.294 (9.523)	-	0.298 (2.04)	-	0.746 (16.129)	0.615 (16)	0.921 (17.141)	0.526 (11.764)
37	<i>T. veride</i>	-	-	-	-	-	-	-	-	-	-	-	0.526 (11.764)
38	<i>Verticillium alboatrum</i>	0.348 (12.5)	-	-	-	-	-	0.298 (4.08)	-	0.447 (9.67)	-	-	0.526 (11.764)
39	<i>V. chlamydosporium</i>	-	-	-	-	-	-	-	-	-	0.616 (16)	-	-
40	<i>V. lecanii</i>	-	-	-	-	0.441 (14.285)	-	-	-	-	-	-	-
41	White sterile mycelia	-	0.270 (8.333)	-	0.263 (13.333)	-	0.441 (20)	-	-	0.746 (16.12)	-	-	0.394 (8.823)
42	Green sterile mycelia	-	-	-	-	-	-	0.289 (2.04)	-	-	-	-	-
43	Yellow sterile mycelia	-	-	-	-	-	-	-	-	-	0.307 (8)	-	0.263 (5.882)

Table 2.3.9. Bimonthly variation in the population of fungal species per gram dry soil X 10³ in Pine forest soil at 0-10 cm depth (February- 2002 -December -2003). The value in the parentheses is the relative abundance

Sl No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A 03	J 03	A 03	O 03	D 03
1	<i>Absidia corymbifera</i>	-	-	-	-	0.937 (13.333)	-	-	-	-	-	0.806 (12.5)	-
2	<i>Acremonium butyris</i>	-	0.746 (11.904)	-	1.111 (24.137)	-	-	-	0.333 (6.666)	0.781 (11.627)	-	0.322 (5)	-
3	<i>A. rutilum</i>	-	0.373 (5.952)	-	-	-	-	-	-	0.312 (4.65)	-	-	-
4	<i>A. murorum</i>	-	-	1.475 (20.93)	-	-	-	0.410 (6)	-	-	-	-	-
5	<i>A. strictum</i>	-	-	-	-	-	-	-	0.757 (16.666)	-	-	-	-
6	<i>Aspergillus candidus</i>	-	-	-	-	-	0.735 (15.62)	-	-	-	-	-	1.129 (22.58)
7	<i>A. flavus</i>	-	-	-	-	0.468 (6.666)	-	-	-	-	-	0.483 (7.5)	-
8	<i>A. fumigatus</i>	-	-	-	-	-	-	-	-	0.625 (9.30)	2.153 (31.818)	2.266 (42.5)	-
9	<i>A. niger</i>	0.845 (18.75)	0.597 (9.523)	-	0.476 (10.344)	-	-	-	-	-	-	-	-
10	<i>Cladosporoides cladosporoides</i>	-	-	-	-	-	0.882 (18.75)	1.506 (22)	0.909 (20)	-	-	-	-
11	<i>C. sphaerospermum</i>	-	0.746 (11.904)	-	-	-	-	-	-	-	-	-	-
12	<i>Eupenicillium brefeldianum</i>	-	-	-	-	-	-	-	-	-	0.153 (2.27)	-	-
13	<i>E. javanicum</i>	-	-	0.655 (9.302)	-	-	-	-	-	-	-	-	-
14	<i>Fusarium culmorum</i>	-	0.895 (14.285)	-	-	-	-	-	-	-	-	-	-
15	<i>F. poae</i>	-	0.746 (11.904)	-	-	-	-	-	-	-	-	0.322 (5)	0.4 (9.677)
16	<i>Gaeumannomyces graminis</i>	-	-	-	-	-	-	-	0.454 (10)	-	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A 03	J 03	A 03	O 03	D 03
17	<i>Humicola fuscoatra</i>	0.422 (9.375)	-	0.447 (7.142)	0.819 (11.627)	-	0.781 (11.111)	-	0.547 (8)	0.312 (4.65)	-	-	-
18	<i>Mucor circinelloides</i>	-	-	-	-	-	0.441 (9.37)	-	-	-	-	-	-
19	<i>M. hiemalis</i>	-	-	-	-	-	1.718 (24.444)	0.273 (4)	-	-	-	0.644 (10)	-
20	<i>M. racemosus</i>	0.704 (15.625)	-	-	-	-	-	-	-	-	-	-	0.666 (16.129)
21	<i>Penicillium brevicompactum</i>	0.563 (12.5)	0.597 (9.523)	0.655 (9.302)	-	0.625 (8.888)	1.47 (31.25)	-	0.606 (13.333)	0.156 (2.32)	1.846 (27.27)	-	0.4 (9.677)
22	<i>P. canescens</i>	-	-	-	-	-	-	-	-	0.625 (9.30)	-	0.161 (2.5)	-
23	<i>P. chrysogenum</i>	0.845 (18.75)	-	-	0.476 (10.344)	-	-	-	-	-	-	-	0.533 (12.903)
24	<i>P. decumbens</i>	-	-	-	-	0.312	-	-	-	-	-	-	-
25	<i>P. frequentans</i>	0.281 (6.25)	-	-	-	0.312 (4.444)	-	0.273 (4)	-	-	-	-	-
26	<i>P. granulatum</i>	-	-	0.491 (6.976)	0.793 (17.241)	-	-	-	-	-	-	-	-
27	<i>P. janthinellum</i>	-	-	-	-	-	-	-	-	-	0.153 (2.27)	-	-
28	<i>P. lanosum</i>	-	-	-	-	-	0.588 (12.5)	-	0.454 (10.003)	-	-	-	-
29	<i>P. restrictum</i>	-	-	-	-	-	-	0.410 (6)	-	-	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A 03	J 03	A 03	O 03	D 03
30	<i>P. stoloniferum</i>	-	-	-	-	-	-	0.958 (14)	-	-	-	-	-
31	<i>Pythium intermedium</i>	-	-	1.803 (25.581)	0.317 (6.896)	-	-	1.780 (26)	-	3.125 (46.511)	0.153 (2.27)	-	-
32	<i>Scopulariopsis brumptii</i>	-	-	-	-	1.093 (15.555)	-	-	-	-	-	-	-
33	<i>Syncephalastrum racemosum</i>	-	-	-	-	-	-	-	-	-	-	0.322 (5)	1.129 (22.583)
34	<i>Trichoderma koningii</i>	-	-	-	0.634 (8.333)	-	-	-	0.757 (16.666)	0.781 (11.62)	1.384 (20.454)	-	-
35	<i>T. hematium</i>	0.281 (6.25)	0.555 (9.523)	-	-	-	-	-	-	-	-	-	-
36	<i>T. verde</i>	-	-	1.174 (16.279)	-	0.468 (6.666)	0.588 (12.5)	-	-	-	-	-	-
37	<i>Verticillium albo-atrum</i>	-	-	-	-	-	-	0.410 (6)	-	-	0.769 (11.36)	-	-
38	<i>V. nigriscens</i>	-	-	-	-	-	-	-	-	0.156 (2.32)	-	-	-
39	<i>White sterile mycelia</i>	0.281 (6.25)	0.447 (7.142)	-	-	-	-	0.273 (4)	-	-	0.153 (2.27)	-	0.266 (6.451)
40	<i>Brown sterile mycelia</i>	-	-	-	0.317 (6.896)	0.312 (4.444)	-	-	-	-	-	0.322 (5)	-
41	<i>Yellow sterile mycelia</i>	-	-	-	-	-	-	-	0.303 (6.666)	-	-	0.322 (5)	-

Table 2.3.10. Bimonthly variation in the population of fungal species per gram dry soil X 10³ in Pine forest soil at 10-20 cm depth (February- 2002 - December 2003). The value in the parentheses is the relative abundance.

Sl no	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A 03	J 03	A 03	O 03	D 03
1	<i>Absidia cylindrospora</i>	-	-	-	-	-	-	0.281 (9.55)	-	-	-	-	-
2	<i>A. corymbifera</i>	-	-	0.322 (5.714)	-	1.060 (19.444)	-	-	-	-	-	-	-
3	<i>Acremonium butyris</i>	-	-	-	1.06 (26.166)	-	-	-	-	-	0.447 (13.043)	-	-
4	<i>A. murorum</i>	-	-	1.129 (20)	-	-	-	-	-	-	-	-	-
5	<i>Aspergillus candidus</i>	-	-	-	-	-	0.606 (16)	-	-	-	-	-	0.684 (21.739)
6	<i>A. flavus</i>	-	-	-	-	0.454 (8.333)	-	-	-	-	-	0.333 (10)	-
7	<i>A. fumigatus</i>	-	-	-	-	-	-	-	0.298 (8.695)	2.424 (40)	-	0.666 (20)	-
8	<i>A. niger</i>	1.25 (2.5)	-	-	0.303 (8.333)	-	-	-	0.447 (13.043)	-	-	-	-
9	<i>Cladosporium cladosporioides</i>	-	-	-	-	-	0.757 (20)	0.281 (9.55)	-	-	-	-	-
10	<i>Eupenicillium brefeldianum</i>	0.277 (5.555)	-	-	0.757 (20.833)	-	-	-	-	-	-	-	-
11	<i>Fusarium culmorum</i>	-	1.044 (23.333)	-	-	-	-	-	-	-	-	-	-
12	<i>F. poae</i>	-	0.895 (20)	-	-	-	-	-	-	-	-	-	0.273 (8.695)
13	<i>Gladiolium catenulatum</i>	0.555 (11.111)	-	-	-	-	-	0.555 (19.04)	-	-	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A 03	J 03	A 03	O 03	D 03
14	<i>Humicola fuscoatra</i>	-	0.298 (6.666)	-	-	0.606 (11.111)	-	0.281 (9.55)	0.447 (13.043)	0.151 (2.5)	-	0.333 (10)	-
15	<i>Mortierella hyalina</i>	-	-	-	-	-	-	0.281 (9.55)	-	-	-	-	-
16	<i>M. polycephala</i>	-	0.447 (10)	-	0.454 (12.5)	-	-	-	-	-	-	-	-
17	<i>Mucor circinelloides</i>	-	-	-	-	-	1.060 (28)	-	-	-	-	-	-
18	<i>M. hiemalis</i>	-	-	-	-	1.363 (25)	-	-	-	-	-	-	-
19	<i>M. racemosus</i>	0.694 (13.888)	-	0.483 (8.571)	-	-	-	-	-	-	-	-	0.410 (13.043)
20	<i>Nectria ventricosa</i>	-	-	-	-	-	-	-	0.597 (17.391)	-	-	-	-
21	<i>Ordiendron griseum</i>	0.277 (5.555)	-	-	-	-	-	-	-	-	-	-	-
22	<i>O. truncatum</i>	-	-	-	-	-	-	-	-	0.757 (12.5)	-	-	-
23	<i>Paecilomyces cameus</i>	-	-	-	-	-	-	0.694 (23.809)	-	-	-	-	-
24	<i>Penicillium brevicompactum</i>	0.416 (8.333)	0.447 (10)	0.806 (14.285)	-	0.454 (8.333)	-	0.138 (4.79)	0.895 (26.086)	-	0.447 (13.043)	-	0.547 (17.931)
25	<i>P. chrysogenum</i>	0.416 (8.333)	-	-	-	0.757 (13.888)	-	-	-	-	-	-	0.547 (17.391)
26	<i>P. funiculosus</i>	0.277 (5.555)	-	-	-	-	-	0.281 (9.52)	-	-	0.895 (26.086)	-	-
27	<i>P. granulatum</i>	-	-	-	0.303 (8.333)	-	-	-	-	-	-	-	-
28	<i>P. janthinellum</i>	-	-	-	-	-	-	-	-	0.303 (5)	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A 03	J 03	A 03	O 03	D 03
29	<i>P. jensenii</i>	-	-	0.483 (8.571)	-	-	-	-	-	-	-	-	-
30	<i>P. lanosum</i>	-	-	-	-	-	0.606 (16)	-	-	-	-	-	-
31	<i>Phytophthora cactorum</i>	-	-	-	-	-	-	-	-	0.151 (2.5)	-	-	-
32	<i>Pythium intermedium</i>	-	-	1.451 (25.714)	0.606 (16.666)	-	-	-	-	1.969 (32.5)	-	-	-
33	<i>Scopulariopsis brumptii</i>	-	-	-	-	0.454 (8.333)	0.303 (8)	-	-	-	-	-	-
34	<i>Synccephalastrum racemosum</i>	-	-	-	-	-	-	-	-	-	-	0.666 (20)	-
35	<i>Trichoderma koningii</i>	0.555 (11.111)	0.746 (16.666)	-	0.303 (8.333)	-	-	-	0.447 (13.043)	0.303 (5)	0.597 (17.391)	0.666 (20)	0.410 (13.043)
36	<i>T. harzianum</i>	-	-	-	-	-	-	-	-	-	0.746 (21.739)	-	-
37	<i>T. veride</i>	-	-	0.967 (17.142)	-	0.303 (5.555)	0.454 (12)	-	-	-	-	-	-
38	<i>White sterile mycelia</i>	-	-	-	-	-	-	0.138 (4.76)	0.298 (8.695)	0.151 (2.5)	0.298 (8.695)	0.333 (10)	-
39	<i>Brown sterile mycelia</i>	-	-	-	-	-	-	-	-	-	-	0.333 (10)	0.273 (8.695)

Table 2.3.11 Bimonthly variation in the population of fungal species per gram dry soil X 10³ in Pine forest soil at 20-30 cm depth during the periods February- December 2002-2003. The value in the parentheses is the relative abundance.

Sl No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A 03	J 03	A 03	O 03	D 03
1	<i>Absidia cylindrospora</i>	-	-	-	-	-	-	-	-	-	-	0.447 (16.666)	-
2	<i>A. corymbifera</i>	-	-	0.468 (10.714)	-	0.606 (16.666)	-	-	-	-	-	-	-
3	<i>Acremonium butyris</i>	-	-	-	0.819 (20.833)	-	-	-	-	0.447 (14.28)	-	-	-
4	<i>A. rutilum</i>	-	-	-	-	-	-	-	0.294 (5.882)	-	-	-	-
5	<i>A. kiliense</i>	-	-	-	-	-	-	-	0.441 (8.823)	-	-	-	-
6	<i>A. murorum</i>	-	-	0.937 (21.428)	-	-	-	-	-	-	-	-	-
7	<i>A. strictum</i>	-	-	-	-	-	-	-	-	-	-	0.285 (7.142)	-
8	<i>Aspergillus candidus</i>	-	-	-	-	0.454 (12.5)	0.579 (21.052)	-	-	-	-	-	0.555 (21.052)
9	<i>A. carneus</i>	-	-	-	-	-	-	-	-	0.298 (9.52)	-	-	-
10	<i>A. flavus</i>	-	-	-	-	0.303 (8.333)	-	-	-	-	-	0.714 (17.857)	-
11	<i>A. fumigatus</i>	-	-	-	-	-	-	-	0.588 (11.764)	-	-	1 (25)	-
12	<i>A. niger</i>	1.428 (25.641)	-	-	0.327 (8.333)	-	-	-	-	-	-	-	-
13	<i>Cladosporium cladosporioides</i>	-	-	-	-	-	0.434 (15.789)	0.422 (12.5)	1.323 (26.470)	-	-	-	-

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A 03	J 03	A 03	O 03	D 03
14	<i>Eupenicillium brefeldianum</i>	0.428 (7.692)	-	-	0.655 (16.666)	-	-	-	-	-	-	-	-
15	<i>Fusarium culmorum</i>	-	0.447 (12.5)	-	-	-	-	-	-	-	-	-	-
16	<i>F. poae</i>	-	0.598 (16.666)	-	-	-	-	-	-	-	-	-	0.416 (15.789)
17	<i>Humicola fuscoatra</i>	0.428 (7.692)	-	-	-	0.454 (12.5)	-	0.563 (16.666)	-	1.194 (38.09)	-	0.285 (7.142)	-
18	<i>Mortierella bisporalis</i>	-	0.746 (20.833)	-	-	-	-	-	-	-	-	-	-
19	<i>M. polycephala</i>	-	0.447 (12.5)	0.312 (7.142)	0.491 (12.5)	-	-	-	-	-	-	-	-
20	<i>Mucor circinelloides</i>	-	-	-	-	-	0.434 (15.789)	-	-	-	-	-	-
21	<i>M. hiemalis</i>	-	-	-	-	0.909 (25)	-	0.281 (8.33)	-	-	-	-	-
22	<i>M. racemosus</i>	0.571 (10.256)	-	-	-	-	-	-	-	-	-	-	0.138 (5.263)
23	<i>Oidiodendron griseum</i>	-	-	-	-	-	-	-	0.294 (5.882)	-	-	-	-
24	<i>O. tenuissimum</i>	-	-	-	-	-	-	-	-	0.298 (9.52)	-	-	-
25	<i>Paecilomyces carneus</i>	-	-	-	-	-	-	0.281 (8.33)	-	-	-	-	-
26	<i>Penicillium brevicompactum</i>	0.428 (7.692)	0.746 (20.833)	0.937 (21.428)	-	0.303 (8.333)	0.724 (26.375)	-	0.882 (17.647)	-	-	0.428 (10.714)	0.416 (15.789)
27	<i>P. chrysogenum</i>	-	-	-	-	0.606 (16.666)	-	-	-	-	-	-	0.416 (15.789)

SI No	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A 03	J 03	A 03	O 03	D 03
28	<i>P. granulatum</i>	-	-		0.491 (12.5)	-	-	-	-	-	-	-	-
29	<i>P. jensenii</i>	-	-	0.312 (7.142)			-	0.985 (29.16)	0.441 (8.823)	-	0.447 (16.666)	-	-
30	<i>P. oxalicum</i>	0.285 (5.128)	-	-	-	-	-	-	0.294 (5.882)	-	-	-	-
31	<i>P. purpurogenum</i>	-	-	-	-	-	-	0.563 (16.66)	-	-	-	-	-
32	<i>Pythium intermedium</i>	0.714 (12.82)		0.781 (17.857)	0.491 (12.5)	-	-	-	-	-	-	0.285 (7.142)	-
33	<i>Scopulariopsis brumptii</i>	-	-	-	-	-	0.289 (10.526)	-	-	-	0.447 (16.666)	-	-
34	<i>Synccephalastrum racemosum</i>	-	-	-	-	-	-	-	-	-	-	0.285 (7.142)	-
35	<i>Trichoderma koningii</i>	0.571 (10.256)	-	-	-	-	-	-	0.441 (8.823)	-	1.343 (50)	0.571 (15.789)	0.416 (15.789)
36	<i>T. veride</i>	-	-	0.625 (14.285)	0.491 (12.5)	-	-	-	-	-	-	-	0.277 (10.526)
37	<i>Verticillium alboatrum</i>	-	-	-	-	-	-	-	-	0.447 (14.28)	-	-	-
38	<i>Brown sterile mycelia</i>	-	-	-	-	-	0.289 (10.526)	0.281 (8.33)	-	-	-	-	-
39	<i>Orange sterile mycelia</i>	0.714 (12.82)	-	-	-	-	-	-	-	0.447 (14.28)	-	-	-

Table 2.3.12. Bimonthly variation in the population of bacterial species per gram dry soil $\times 10^3$ in Khloo Paiung forest soil at 0-10 cm depth (February 2002 - December 2003). The value in the parentheses is the relative abundance.

Sl no	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
1	<i>Arthrobacter sp</i>	0.6 (21.428)	-	2.049 (15.923)	8.181 (32.727)	2.796 (14.224)	7.416 (41.013)	3.125 (27.21)	6.896 (40.609)	7.672 (30.902)	6.727 (36.815)	1.587 (15.625)	-
2	<i>Azotobacter sp</i>	-	-	-	-	3.389 (17.241)	-	-	-	-	-	1.764 (17.187)	-
3	<i>Bacillus cereus</i>	-	-	-	-	8.559 (18.103)	-	-	-	-	3.09 (16.915)	1.984 (19.531)	1.956 (17.197)
4	<i>Bacillus subtilis</i>	0.8 (28.571)	14.298 (80.295)	4.09 (31.847)	6.818 (27.272)	-	5.833 (32.358)	-	3.017 (17.766)	0.689 (2.77)	2.454 (13.432)	-	2.246 (19.745)
5	<i>Bacillus sp</i>	0.666 (23.809)	-	2.213 (17.197)	4.818 (19.279)	1.44 (7.327)	-	4.687 (40.816)	-	-	2.181 (11.490)	1.686 (16.406)	2.101 (18.471)
6	<i>Micrococcus sp</i>	-	-	1.639 (12.738)	-	2.542 (12.931)	-	2.343 (20.408)	3.448 (20.304)	11.551 (46.527)	2.727 (14.925)	3.174 (31.25)	3.26 (28.662)
7	<i>Pseudomonas sp</i>	0.733 (26.19)	3.508 (19.704)	1.639 (12.738)	5.181 (20.727)	5.932 (30.172)	2.75 (15.207)	-	3.620 (21.319)	-	-	-	1.811 (15.923)
8	<i>Rhizobium sp</i>	-	-	1.229 (9.544)	-	-	2.083 (11.52)	1.328 (11.564)	-	4.91 (19.791)	1.09 (5.970)	-	-

Table 2.3.13. Bimonthly variation in the population of bacterial species per gram dry soil X 10³ in Khlooi Paiung forest soil at 10-20 cm depth (February 2002 - December 2003). The value in the parentheses is the relative abundance.

Sl no	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
1	<i>Arthrobacter sp</i>	-	-	1.953 (17.605)	6.129 (47.5)	1.854 (20.175)	4.687 (43.478)	2.014 (27.835)	6.465 (42.613)	3.688 (31.69)	4.561 (36.363)	1.515 (17.241)	-
2	<i>Azotobacter sp</i>	-	-	-	-	1.129 (12.28)	-	-	-	-	-	1.439 (16.379)	-
3	<i>Bacillus cereus</i>	-	-	-	-	0.806 (8.771)	-	-	-	-	2.017 (16.083)	1.59 (18.103)	1.515 (19.081)
4	<i>Bacillus subtilis</i>	0.855 (38.235)	8.474 (54.945)	2.734 (24.647)	3.629 (28.125)	1.451 (21.929)	3.125 (28.985)	-	2.241 (14.772)	-	1.140 (9.09)	-	1.742 (22.77)
5	<i>Bacillus sp</i>	0.657 (29.411)	3.135 (20.329)	1.562 (14.084)	-	2.016 (18.75)	2.343 (21.739)	2.835 (39.175)	-	-	1.491 (11.888)	1.439 (16.379)	1.363 (17.821)
6	<i>Micrococcus sp</i>	-	-	1.796 (16.197)	0.725 (5.625)	-	-	1.492 (20.618)	3.103 (20.454)	4.918 (42.253)	2.631 (20.979)	2.803 (31.896)	3.03 (39.606)
7	<i>Pseudomonas sp</i>	0.657 (29.411)	3.813 (28.57)	1.796 (16.197)	2.419 (16.901)	2.016 (18.75)	-	-	3.362 (22.159)	-	-	-	-
8	<i>Rhizobium sp</i>	-	-	1.171 (10.563)	-	-	0.625 (5.797)	0.895 (12.371)	-	3.032 (26.056)	0.701 (5.594)	-	-

Table 2.3.14. Bimonthly variation in the population of bacterial species per gram dry soil X 10³ in Khloo Paiung forest soil at 20-30 cm depth (February 2002 - December 2003). The value in the parentheses is the relative abundance.

Sl no	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
1	<i>Arthrobacter sp</i>	-	-	1.285 (20.00)	2.295 (25.668)	1.015 (13.829)	3.409 (63.280)	0.714 (22.222)	3.688 (39.13)	3.145 (30.708)	-	0.579 (17.391)	-
2	<i>Azotobacter sp</i>	-	-	-	-	0.703 (9.574)	-	-	-	-	-	0.579 (17.391)	-
3	<i>Bacillus cereus</i>	-	-	-	-	-	-	-	-	-	1.491 (13.934)	0.724 (21.739)	-
4	<i>Bacillus subtilis</i>	0.657 (33.333)	2.333 (65.116)	2 (31.111)	2.459 (27.522)	1.328 (18.085)	1.439 (26.760)	-	1.639 (17.391)	-	0.964 (9.01)	-	0.955 (28.888)
5	<i>Bacillus sp</i>	0.657 (33.333)	-	1.214 (18.888)	2.131 (23.853)	1.328 (18.085)	-	1.142 (35.555)	-	-	1.315 (12.295)	0.507 (15.217)	0.882 (26.666)
6	<i>Micrococcus sp</i>	-	-	1.071 (16.666)	-	1.406 (19.148)	-	0.714 (22.222)	1.885 (20)	4.193 (40.944)	2.631 (24.522)	0.942 (28.26)	1.47 (44.444)
7	<i>Pseudomonas sp</i>	-	-	0.857 (13.333)	2.049 (22.935)	1.562 (21.276)	0.606 (11.267)	-	2.213 (23.478)	-	3.421 (31.967)	-	-
8	<i>Rhizobium sp</i>	0.657 (33.333)	1.25 (34.883)	-	-	-	-	0.642 (20)	-	2.903 (28.346)	0.877 (8.196)	-	-

Table 2.3.15. Bimonthly variation in the population of bacterial species per gram dry soil X 10³ in Khloo Langdoh forest soil at 0-10 cm depth (February 2002 - December 2003). The value in the parentheses is the relative abundance.

Sl no	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A 03	J 03	A 03	O 03	D 03
1	<i>Arthrobacter sp</i>	-	2.08 (29.702)	3.676 (25.380)	-	0.859 (6.547)	1.25 (13.178)	1.209 (9.868)	2.857 (32.984)	10.625 (49.097)	-	-	-
2	<i>Azotobacter sp</i>	-	-	-	-	-	-	-	1.666 (13.333)	-	-	-	-
3	<i>Bacillus cereus</i>	-	-	1.323 (9.137)	-	1.25 (9.523)	-	-	2.083 (16.666)	-	1.119 (12.396)	-	-
4	<i>Bacillus subtilis</i>	1.234 (29.411)	2.708 (38.613)	4.632 (31.979)	3.257 (23.118)	3.671 (27.976)	1.47 (15.503)	6.048 (49.342)	6.746 (44.502)	3.125 (14.44)	1.083 (8.666)	2.91 (32.231)	1.066 (15.384)
5	<i>Bacillus sp</i>	1.049 (25)	1.388 (19.801)	-	3.712 (26.344)	3.125 (23.809)	-	1.451 (13.157)	3.412 (22.513)	1.25 (5.776)	2.25 (18)	2.238 (24.793)	1.933 (27.884)
6	<i>Micrococcus sp</i>	0.864 (20.588)	-	2.647 (18.274)	4.545 (32.258)	-	4.411 (46.511)	1.935 (15.789)	-	6.64 (30.685)	1.416 (11.333)	1.492 (16.528)	1.266 (18.269)
7	<i>Pseudomonas sp</i>	-	-	2.205 (15.228)	2.579 (18.279)	3.515 (26.785)	1.397 (14.728)	-	-	-	2.343 (32)	1.268 (14.049)	-
8	<i>Rhizobium sp</i>	1.049 (25)	0.833 (11.881)	-	-	0.703 (5.357)	0.955 (10.077)	1.451 (11.842)	-	-	-	-	2.666 (38.461)

Table 2.3.16. Bimonthly variation in the population of bacterial species per gram dry soil X 10³ in Khloo Langdoh forest soil at 10-20 cm depth (February 2002 - December 2003). The value in the parentheses is the relative abundance.

Sl no	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
1	<i>Arthrobacter sp</i>	-	1.575 (35.38)	2.941 (31.707)	2.083 (30.909)	0.757 (11.764)	0.588 (10.526)	0.606 (7.692)	2.424 (30.769)	6.304 (46.524)	1.171 (15.789)	-	1.052 (18.604)
2	<i>Azotobacter sp</i>	-	-	-	-	1.129 (12.28)	-	-	-	-	-	1.439 (16.379)	-
3	<i>Bacillus cereus</i>	-	-	-	-	-	-	-	-	-	1.484 (20)	1.086 (12.931)	-
4	<i>Bacillus subtilis</i>	1.036 (31.481)	1.027 (23.07)	3.823 (24.390)	-	1.66 (25.882)	0.882 (15.789)	2.954 (37.5)	3.409 (43.269)	2.173 (16.042)	-	2.681 (31.896)	-
5	<i>Bacillus sp</i>	0.609 (18.518)	0.616 (13.846)	1.25 (10.365)	2.013 (26.363)	1.136 (17.647)	-	1.06 (13.461)	1.136 (14.423)	1.304 (9.625)	1.171 (15.789)	2.101 (25)	1.710 (32.558)
6	<i>Micrococcus sp</i>	0.731 (22.222)	1.232 (27.692)	2.205 (18.292)	2.083 (27.272)	1.363 (21.176)	2.573 (46.052)	1.212 (15.384)	-	3.768 (27.807)	1.171 (15.789)	1.376 (16.379)	1.052 (18.604)
7	<i>Pseudomonas sp</i>	-	-	1.102 (15.293)	1.18 (15.454)	1.129 (12.28)	0.735 (13.157)	1.136 (14.423)	0.909 (11.538)	-	1.538 (31)	1.159 (13.793)	-
8	<i>Rhizobium sp</i>	0.914 (27.777)	-	-	-	-	0.808 (14.473)	0.909 (11.538)	-	-	-	-	1.973 (34.883)

Table 2.3.17. Bimonthly variation in the population of bacterial species per gram dry soil X 10³ in Khloo Langdoh forest soil at 20-30 cm depth (February 2002 - December 2003). The value in the parentheses is the relative abundance.

Sl no	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A 03	J 03	A 03	O 03	D 03
1	<i>Arthrobacter</i> sp	0.813 (33.333)	0.878 (38.235)	2.72 (35.238)	0.657 (21.276)	0.808 (17.741)		0.522 (12.962)	0.820 (27.5)	5.97 (45.197)	-	-	-
2	<i>Azotobacter</i> sp	-	-	-	-	-	-	-	-	-	-	-	0.986 (24.59)
3	<i>Bacillus cereus</i>	-	-	-	-	-	-	-	0.923 (21.052)	-	0.694 (10)	-	-
4	<i>Bacillus subtilis</i>	0.872 (35.714)	0.810 (35.294)	2.352 (30.476)	0.789 (25.531)	1.102 (24.193)	0.661 (19.148)	1.343 (33.333)	1.268 (42.5)	1.716 (12.994)	-	2.083 (30)	-
5	<i>Bacillus</i> sp	-	-	-	0.657 (21.276)	0.882 (19.354)	0.735 (21.276)	0.597 (14.814)	0.447 (15)	1.044 (7.909)	0.769 (17.543)	1.736 (25)	0.986 (24.59)
6	<i>Micrococcus</i> sp	-	-	1.47 (20)	0.986 (31.914)	0.661 (14.516)	1.544 (44.680)	0.597 (14.814)	-	3.731 (28.248)	1.153 (26.315)	1.319 (19)	-
7	<i>Pseudomonas</i> sp	-	0.675 (29.411)	1.102 (14.285)	-	1.102 (24.193)	0.514 (14.893)	0.97 (24.074)	0.447 (15)	-	1.417 (35.087)	1.111 (16)	1.907 (47.54)
8	<i>Rhizobium</i> sp	0.755 (30.952)	-	-	-	-	-	-	-	0.746 (5.649)	-	-	-

Table 2.3.18. Bimonthly variation in the population of bacterial species per gram dry soil X 10³ in Pine forest soil at 0- 10cm depth (February 2002 - December 2003). The value in the parentheses is the relative abundance.

Sl no	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
1	<i>Arthrobacter</i> sp	-	-	3.278 (16.460)	0.952 (21.428)	0.781 (16.393)	1.893 (24.038)	2.26 (26.829)	-	9.375 (49.586)	-	6.451 (44.444)	2 (25)
2	<i>Azotobacter</i> sp	-	-	-	-	-	-	-	1.171 (17.441)	-	-	-	-
3	<i>Bacillus subtilis</i>	0.985 (21.538)	1.716 (30.263)	6.475 (32.510)	-	-	1.136 (14.423)	3.424 (40.650)	-	-	-	-	-
4	<i>Bacillus</i> sp	-	-	1.323 (8.230)	0.793 (17.857)	0.781 (16.393)	3.333 (42.307)	-	1.562 (23.255)	-	-	-	1.733 (21.666)
5	<i>Micrococcus</i> sp	1.267 (27.692)	1.492 (26.31)	-	0.634 (14.285)	0.937 (19.672)	-	-	1.25 (18.604)	8.593 (45.454)	1.538 (55.555)	-	1.733 (22.5)
6	<i>Pseudomonas</i> sp	0.915 (20)	1.119 (19.736)	8.524 (42.798)	0.714 (16.071)	1.093 (22.95)	-	2.739 (32.52)	-	-	-	8.064 (55.555)	-
7	<i>Rhizobium</i> sp	1.408 (30.769)	1.343 (23.684)	-	1.349 (30.357)	1.171 (24.590)	1.515 (19.230)	-	2.734 (40.697)	0.937 (4.958)	1.230 (44.444)	-	2.466 (30.833)

Table 2.3.19. Bimonthly variation in the population of bacterial species per gram dry soil X 10³ in Pine forest soil at 10-20cm depth (February 2002 - December 2003). The value in the parentheses is the relative abundance.

Sl no	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
1	<i>Arthrobacter sp</i>	-	-	-	0.606 (22.857)	-	0.491 (10.344)	2.22 (27.35)	-	7.575 (48.543)	-	3.455 (32.865)	-
2	<i>Azotobacter sp</i>	-	-	-	-	-	-	-	0.681 (16.363)	-	-	-	-
3	<i>Bacillus subtilis</i>	-	-	2.258 (30.434)	0.681 (25.714)	-	0.983 (20.689)	3.125 (38.461)	-	-	-	-	-
4	<i>Bacillus sp</i>		-	1.209 (16.304)	0.606 (22.857)	0.53 (16.279)	1.885 (39.655)	-	1.06 (25.454)	-	-	-	0.89 (27.083)
5	<i>Micrococcus sp</i>	0.813 (33.333)	1.492 (36.363)	1.451 (19.565)	-	0.757 (23.255)	1.393 (29.310)	-	0.757 (18.181)	6.969 (44.66)	1.153 (46.875)	-	1.164 (35.416)
6	<i>Pseudomonas sp</i>	0.872 (35.714)	1.417 (34.545)	2.5 (33.695)	-	0.909 (27.906)	-	2.777 (34.188)	-	-	-	7.058 (67.132)	-
7	<i>Rhizobium sp</i>	0.755 (30.952)	1.194 (29.090)	-	0.757 (28.57)	1.06 (32.558)	-	-	1.666 (40)	1.06 (6.796)	1.307 (53.123)	-	1.232 (37.5)

Table 2.3.20. Bimonthly variation in the population of bacterial species per gram dry soil X 10³ in Pine forest soil at 20-30cm depth (February 2002 - December 2003). The value in the parentheses is the relative abundance.

Sl no	Fungal species	F 02	A 02	J 02	A 02	O 02	D 02	F 03	A03	J 03	A 03	O 03	D 03
1	<i>Arthrobacter sp</i>	-	-	-	1.229 (25.862)	0.606 (20)	-	1.267 (30)	0.735 (24.39)	2.462 (44)	-	1.428 (26.666)	-
2	<i>Bacillus subtilis</i>	-	2.388 (33.333)	0.625 (25)	-	0.833 (31.428)	0.588 (18.604)	1.619 (38.333)	-	-	-	-	-
3	<i>Bacillus sp</i>	-	-	0.312 (12.5)	1.065 (22.413)	-	1.323 (41.860)	-	0.588 (19.512)	1.119 (20)	1.119 (29.411)	-	0.694 (27.777)
4	<i>Micrococcus sp</i>	0.928 (39.393)	2.238 (35.555)	0.703 (28.125)	-	0.606 (22.857)	0.514 (16.27)	-	0.514 (17.073)	2.014 (36)	(37.254)	-	0.833 (33.333)
5	<i>Pseudomonas sp</i>	0.714 (30.303)	-	-	1.147 (24.137)	-	0.735 (23.255)	1.338 (31.666)	-	-	-	3.214 (60)	-
6	<i>Rhizobium sp</i>	0.714 (30.303)	2.089 (31.111)	0.859 (34.375)	1.393 (29.310)	0.681 (25.714)	-	-	1.176 (39.024)	-	1.268 (33.333)	0.714 (13.333)	0.972 (38.888)

2. 4. Discussion

2. 4. 1. Fungal population

The peak in fungal population during raining season in both the year could be due to favorable soil moisture and temperature conditions. The increased of fungal population during rainy season was also reported by Yang *et al.*, (2006) which consisted with warmer temperatures favouring fungal growth. Persiani *et al.* (2005) reported that abundance and species density of total mycoflora increased with a more favourable moisture condition of soil. Maximum population observed in the second year during spring season which is also supported by Jha *et al.* (1992).

The relatively low population of fungi coupled with less favourable climatic conditions was the reason for a reduction in the population numbers of fungi during winter month. Tiwari *et al.* (1987) suggested that the presence of soil moisture content was the major factor controlling the distribution of fungi. The higher population of fungi at the surface soil layer than at the sub -surface soil layer may be attributed to variation in nutrient status, at different depth (Balasubramaniam *et al.*, 1972; Scheu and Parkinson, 1994) and moisture regime (Selveraj and Rangaswamy 1978). Surface layer of soil is usually provided with high organic matter content which in presence of adequate moisture supply is acted upon by microorganisms to decompose the complex organic residues into simpler forms; hence the species of microorganisms are higher on surface layer of the soil (Kayang, 2006). Decrease of fungal population with increasing soil depth is related to the organic carbon content of

the soil (Tiwari *et al.*, 1991). Generally, fungi found into deeper layer are slow growing due to unavailability of mineral nutrients and compaction of soil along depth. Additional factors which are not directly linked to the specific environmental conditions found within the soil profiles may also contribute to the differentiation of microbial communities.

2.4. 2. Bacterial population

The improvement of moisture levels, moderation of temperature favoured the maximum build up of the bacterial counts in the rainy season. This finding corroborates with the findings of Rigobella and Nahas, (2004) who reported that in soils under *Eucalyptus* and *Pinus*, the total number of bacteria was higher during summer because of the higher rainfall and air temperature. Soil physical factors like moistures content have been shown to influence bacterial biomass (Clarholm and Rosswall, 1980). Low bacterial population could be due to moisture stress, but according to Gray *et al.*, (1974), Laundelout *et al* (1978) and Kauri (1982), Hogervorst *et al.*, (1996), the abundance of bacteria tends to be highest in winter as has been found for deciduous forest and a coniferous forest. Seasonal fluctuation can be seen in bacterial population as reported by some other workers like Laundelout *et al.*, (1978), Killbertus *et al.*, (1979), Clarholm and Rosswall (1980) also demonstrated changes in the soil bacterial numbers over the years in coniferous forest soil, while Kauri (1982) found peaks in spring and autumn in Swedish beech forest soil.

In all the three forest stands there was a declined of bacterial population, this could be attributed to the reduction of available nutrients. Positive correlation coefficient of bacterial population could be seen with moisture content, organic carbon, total nitrogen and other enzyme activities which indicated the dependence of bacterial population on moisture content and other physico-chemical characteristics of soil.

The increased in the diversity index of the bacterial population in most cases during the rainy season than winter season was probably due to the high moisture content. Even with less acid a significant number of bacterial populations could be observed. Consequently a simple relation between pH and soil bacterial numbers does not always exist. This suggests that other environmental factors are also important in controlling the size of bacterial populations in soil (Schimel *et al.*, 1999). The importance of different environmental factors on numbers of bacteria apparently varies from season to season (Wilkinson *et al.*, 2002).

CHAPTER 3

ANALYSIS OF SOIL PHYSICO-CHEMICAL CHARACTERISTICS IN TWO SACRED GROVES AND PINE FOREST

3.1. Introduction

Plant cover and tree species can have fundamental effects on soil properties. Depending on tree species, there are differences in the leaching of substances from litter. For example, water soluble substances are more easily leached from the leaf litter of deciduous trees than from that of coniferous species (Harris and Safford, 1996, Hongve *et al.*, 2000). Plant dead material is the main source of organic matter in soils and its decomposition by soil microorganisms ensures the recycling of nutrients that can be then reused by plants. Among these, fungi and bacteria play an important role in decomposition and nutrient cycling and as a result influence the biological and chemical properties of soil.

The physical condition and chemical characteristics of soil play an important role in determining the environment in which biological processes take place and can be defined at different spatial and temporal scales (De Vos *et al.*, 1994). The seasonal climatic variations also influenced the soil nutrient contents (Imberger and Chiu, 2002; Rigobelo and Nahas, 2004). The chemical characteristics make a significant contribution in determining the quality and may even determine the maximum quality of a particular soil (Dick, 1994; Hassink, 1997).

Witter *et al.*, (1993) reported that low pH has also been shown to result in a reduction in the size of the soil microbial biomass. Temporal fluctuation in the soil microbial biomass and consequently in microbially bound phosphorus are important (Perrott *et al.*, 1990; Tate *et al.*, 1991) and can significantly influence crop productively (Buchanan and King, 1992). Reddy (1995) reported that soil microorganisms regulate nutrient cycling by affecting the decomposition process that influences the release and retention of nutrients.

Microorganisms are intimately associated with their physical and chemical environment and it is, therefore, conceivable that the temporal dynamics observed will partly reflect adaptation to environmental variables rather than competition between components of the microbial biomass. Thus, it has been emphasized on the recognition of the importance of the soil microorganism in the functioning of the ecosystem has led to an increased interest in measuring the nutrients held in their biomass (Paul and Clark, 1989). Many aspects of soil microbial communities are affected by prevailing conditions with respect to substrate quality and stresses (Soren *et al.*, 2002).

3.2. Methodology

3.2.1. Soil moisture content

The moisture content of soil was determined by oven dry basis. 10 g of freshly collected soil sample was kept in a hot air oven at 105° C for 24 hours.

The percentage moisture content was calculated by the following formula.

$$\text{Moisture content (\%)} = \frac{W_1 - W_2}{W_1}$$

Where, W_1 = initial weight

W_2 = final weight

3.2.2. Soil pH

10 g of freshly collected soil was taken in a beaker containing 50 ml of distilled water. The soil water mixture was stirred for 20 minutes on a magnetic stirrer. The solution was kept overnight and the pH was read by using electronic digital pH meter.

3.2.3. Soil organic carbon

Soil organic carbon was estimated by the method of Anderson and Ingram (1993). Weighed 1 g ground soil (< 0.15 mm) in to a labeled 100 ml conical flask (if the soil was dark, or was suspected to be high in organic matter used about 0.5 g). To this add 10 ml of 5% potassium dichromate solution and allowed it to completely wet the soil or dissolved the standards. 20 ml of sulphuric acid was then added from a fast burette and swirled the mixture gently, allowed to cool it. To this 50 ml of 0.4% barium chloride was added, swirled the mixture thoroughly and then allowed to stand overnight, so as to leave a clear supernatant solution. The blank was run without soil. The supernatant was then transferred into a colorimetric cuvette and measured the optical density by using Hitachi (220) spectrophotometer at 600 nm.

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

Where, W = Weight of soil.

3.2.4. Total nitrogen

The soil total nitrogen was estimated by using the method of Jackson (1973). Weighed 1 g of dried finely ground soil (>2 mm sieve) into a kjeldahl digestion flask and 6 ml of sulphuric acid was added. To this one kjeltabket was added and then the soil sample was digested in a block digester for about half an hour (till the colour turns green). The flask was allowed to cool and diluted with 50 ml of distilled water. The solution was then filtered with Whatman filter paper No. 1. After this, distillation was done in a kjeldahl distillation set with 10 ml of sample solution and 10 ml of 40% sodium hydroxide. The distillate was then collected in a beaker with 5 ml of boric acid indicator till the pink colour turned greenish. The distillate was then titrated against N/140 hydrochloric acid. The titration was stop when the colour turned pink.

$$N\% = \frac{(T - \text{blank}) \times \text{solution volume}}{10^2 \times \text{aliquot vol.} \times \text{sample weight}}$$

where, T = Burette reading

Preparation of boric acid indicator:

10 g of boric acid was dissolved in 1000 ml of distilled water. To this 10 ml of bromocresol green (dissolved 0.1g bromocresol green in 10 ml methanol) and 7 ml methyl red (dissolved 0.07 methyl red in 7 ml of methanol) were added.

3.2.5. Available phosphorous

The available phosphorous was measured by following molybdenum blue method (Allen *et al.*, 1974). Weighed 5g of air-dried sieved soil in a polythene bottle. To this 100 ml of Olsen's reagent was added and it was shaken for 30 minutes on a rotatory shaker. The mixture was filtered through Whatman filter paper No. 44. 10 ml of sample was pipetted into 50 ml volumetric flask. The sample was diluted about two third of the flask. To this 2ml of ammonium molybdate reagent and 2 ml of stannous chloride reagent were added and then the final volume was made up to 50 ml by adding distilled water. Control was maintained without soil sample. After 30 minutes the optical density was read in a Hitachi (220) spectrophotometer at 700 nm. The calibration curve was prepared from the standard and was used to determine mg P in the same aliquot.

$$P\% = \frac{C(\text{mg}) \times \text{solution volume (ml)}}{10^3 \times \text{aliquot (ml)} \times \text{sample weight (g)}}$$

Preparation of reagents

Olsen's reagent

Dissolved 210 g of sodium bicarbonate in water in aspirator and to this 100 ml of 1M sodium hydroxide was added. The final pH was adjusted to 8.5 ± 0.05 .

Ammonium molybdate sulphuric reagent

Dissolved 25 g of ammonium molybdate $[(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}]$ in about 200 ml of water by warming slightly. 280 ml of concentrated sulphuric acid was added (with mixing and cooling) to about 400 ml of water and the solution was mix thoroughly and distilled water was added to make up to 1 l when it was cool. The mixture was then stored in a dark place.

3.2.6. Exchangeable potassium

Exchangeable potassium was measured by using the method of Allen *et al.*, (1974). First, weighed 10 g of air-dried sieved soil in a 500 ml conical flask. To this 250 ml of ammonium acetate solution was added. The mixture was then shaken in a rotatory shaker for 1 hour and was kept overnight. The mixture was then shaken for 5 minutes and was filtered through Whatman filter paper No. 44. The blank was run with extraction only. Potassium was then determined in a flame photometer.

$$K\% = \frac{C(\text{ppm}) \times \text{solution volume (ml)}}{10^4 \times \text{sample weight (g)}}$$

Preparation of reagent extractant (Ammonium acetate)

575 ml of glacial acetic acid was added to 200 ml of water in a 10 l container (preferably polythene). To this 600 ml of 0.880N of ammonia solution was added slowly by cooling. The mixture was then diluted to 10 l with water. The final pH was adjusted to 7 ± 0.05 by adding either few drops of acetic acid or ammonia solution.

3.3. Results

3.3.1. Soil moisture content

The maximum soil moisture content was observed in August and the minimum in February during the study period. In the first year (2002) of study, at surface soil layer (0-10cm), moisture content ranged between 18.6% and 45% in Khloo Langdoh and Khloo Paiung in February and August respectively. At sub surface soil layer (10-20cm, 20-30cm), it ranged from 13.9% and 33.4% in Khloo Langdoh and Khloo Paiung in February and August respectively.

In the second year (2003) of study at surface soil layer (0-10cm), moisture content ranged between 24% and 44.6% in Khloo Langdoh and Khloo Paiung in December and August respectively. At sub surface soil layer (10-20cm, 20-30cm), it ranged from 22.8% and 42% in Khloo Langdoh and Khloo Paiung in December and August respectively (Fig. 3.3.1).

The analysis of variance (ANOVA) showed a significance variation at 0-10cm x 10-20cm x 20-30cm in Khloo Paiung and at 0-10cm x 10-20cm, 0-



10cm x 10-20cm x 20-30cm and at 0-10cm x 20-30cm in Khloo Langdoh and insignificance variation in pine forest (Tables 6.1, 6.2 and 6.3)

In Khloo Paiung the correlation coefficient values of soil moisture content showed a positive correlation with total nitrogen, dehydrogenase, bacterial population and fungal population (Table 6.5). In Khloo Langdoh the correlation coefficient values of soil moisture content showed a positive correlation with total nitrogen, potassium, dehydrogenase, bacterial population and fungal population (Table 6.6). In pine forest the correlation coefficient values of soil moisture content showed a positive correlation with potassium, dehydrogenase, and fungal population (Table 6.7).

3.3.2. Soil pH

The soil pH ranged between 4.84 and 6.5 at the surface soil layer and sub surface soil layer respectively in all the three forest stands.

In the first year (2002) of study, at surface soil layer (0-10cm), the soil pH ranged between 5 and 6.3 in Khloo Langdoh and Khloo Paiung in February and August respectively. At sub surface soil layer (10-20cm, 20-30cm), it ranged between 4.8 and 6.5 in Khloo Langdoh and pine forest in April and June respectively.

In the second year (2003) of study at surface soil layer (0-10cm), the soil pH ranged between 5.1 and 6.5 in Khloo Langdoh and Khloo Paiung in April and June respectively. At sub surface soil layer (10-20cm, 20-30cm), it ranged between 4.9 and 6.4 in Khloo Langdoh and pine forest in June and February respectively (Fig 3.3.2).

The analysis of variance (ANOVA) showed an insignificance variation in all the forest stands (Tables 6.1, 6.2 and 6.3). The correlation coefficient values of soil pH showed negative correlation with all the parameters in all the forest stands (Tables 6.5, 6.6 and 6.7).

3.3.3. Soil organic carbon

The soil organic carbon showed increased percentage between the two sacred groves and the pine forest. It ranged between 2.4% and 0.27% in Khloo Paiung and pine forest in April and December respectively.

In the first year (2002) of study, at surface soil layer (0-10cm), soil organic carbon ranged between 1.5% and 2.4% in pine forest and Khloo Paiung in December and April respectively. At sub surface soil layer (10-20cm), it ranged from 0.5% and 1.7% in pine forest and Khloo Langdoh in April and October respectively. At 20-30cm it ranged between 0.5% and 1.6% in pine forest and Khloo Langdoh in April and October respectively.

In the second year (2003) of study, at surface soil layer, the soil organic carbon ranged between 0.75% and 2.4% in pine forest and Khloo Langdoh in October and August respectively. At sub surface soil layer (10-20cm) it ranged between 0.14% and 1.9% in pine forest and Khloo Langdoh in December and August respectively. At 20-30cm it ranged between 0.27% and 1.59% in pine forest and Khloo Langdoh in December and August respectively (Fig. 3.3.3).

The analysis of variance (ANOVA) showed a significance variation at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in all the three forest stands (Tables 6.1, 6.2 and 6.3).

In Khloo Paiung, the correlation coefficient values of soil moisture content showed a positive correlation with total nitrogen, available phosphorus, potassium, microbial biomass carbon, dehydrogenase, phosphatase, bacterial population and fungal population (Table 6.5). In Khloo Langdoh, the correlation coefficient values of soil organic carbon showed a positive correlation with total nitrogen, available phosphorus, potassium, microbial biomass carbon, dehydrogenase, and bacterial population (Table 6.6). In pine forest the correlation coefficient values of soil organic carbon showed a positive correlation with total nitrogen, available phosphorus, microbial biomass carbon, dehydrogenase, and fungal population (Table 6.7).

3.3.4. Total Nitrogen

The total nitrogen showed increased percentage between the two sacred groves and the pine forest. At surface soil layer it ranged between 0.06% and 0.37% in pine forest and Khloo Langdoh in October 2002 and October 2003 respectively.

In the first year (2002) of study, at surface soil layer, total nitrogen ranged between 0.13% and 0.29% in Khloo Paiung in February and April. There was also increased total nitrogen in December. In Khloo Langdoh it ranged between 0.13% and 0.31% in June and August respectively. In pine forest it ranged between 0.06% and 0.17% in October and June respectively. At sub surface soil layer (10-20cm), it ranged from 0.30% and 0.06% in Khloo

Langdoh and pine forest in October respectively. At 20-30cm it ranged between 0.16% and 0.04% in Khloo Paiung and pine forest in August and October respectively.

In the second year (2003) of study at surface soil layer, total nitrogen ranged between 0.13% and 0.26% in October and August respectively. In Khloo Langdoh it ranged between 0.19% and 0.37% in April and October respectively. In pine forest it ranged between 0.09% and 0.20% in August and April respectively. At sub surface soil layer (10-20cm) it ranged between 0.05% and 0.24% in pine forest and Khloo Langdoh in June and August respectively. At 20-30cm, it ranged between 0.02 % and 0.16% in Khloo Paiung and Khloo Langdoh in June and February respectively (Fig. 3.3.4).

The analysis of variance (ANOVA) showed a significance variation at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in all the three forest stands (Tables 6.1, 6.2 and 6.3).

In Khloo Paiung, the correlation coefficient values of soil moisture content showed a positive correlation with available phosphorus, potassium, organic carbon, microbial biomass carbon, dehydrogenase, phosphatase, moisture content, bacterial population and fungal population (Table 6.5). In Khloo Langdoh, the correlation coefficient values of soil organic carbon showed a positive correlation with dehydrogenase, phosphatase, moisture content, bacterial population and fungal population (Table 6.6). In pine forest the correlation coefficient values of soil organic carbon showed a positive correlation with available phosphorus, organic carbon, microbial biomass carbon, bacterial population and fungal population (Table 6.7).

3.3.5. Available Phosphorus

The available phosphorus in all the three forest stands is high in the two sacred groves than in the pine forest. Available phosphorus is high and low in June and December respectively in both the years. The first year (2002) showed higher amount of available phosphorus than in the second year (2003).

In the first year (2002), at surface soil layer, available phosphorus ranged between 0.009 and 0.051 in pine and Khloo Langdoh forest in December and June respectively. At sub surface soil layer (10-20cm) it ranged between 0.04 and 0.032 in pine and Khloo Langdoh forest in February and June respectively. At 20-30cm, it ranged between 0.004 and 0.02 in Khloo Langdoh in August and February respectively.

In the second year (2003) of study at surface soil layer, available phosphorus ranged between 0.014 and 0.034 in Khloo Langdoh in April and August. At sub surface soil layer (10-20cm), it ranged between 0.007 and 0.013 in pine forest and Khloo Langdoh in April and February respectively. At 20-30cm, it ranged between 0.013 and 0.015 in Khloo Paiung and pine forest in December respectively (Fig 3.3.5).

The analysis of variance (ANOVA) showed a significant variation at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in pine forest and khloo Paiung and at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20cm x 30cm in khloo Langdoh (Tables 6.1, 6.2 and 6.3).

In Khloo Paiung, the correlation coefficient values of available phosphorus showed a positive correlation with, total nitrogen, potassium, organic carbon, phosphatase and bacterial population (Table 6.5). In Khloo Langdoh, the correlation coefficient values of available phosphorus showed a positive correlation with organic carbon, potassium and microbial biomass carbon (Table 6.6). In pine forest, the correlation coefficient values of available phosphorus showed a positive correlation with total nitrogen, organic carbon and microbial biomass carbon (Table 6.7).

3.3.6. Potassium

Potassium in soil is high during winter season and low during rainy season. In the first year (2002) of study, at surface soil layer, potassium ranged between 1.8% and 4.0% in Khloo Paiung and Khloo Langdoh in August and February respectively. At sub surface soil layer (10-20cm) it ranged between 1.5% and 3.75% in Khloo Langdoh and Khloo Paiung in February and December respectively. At 20-30cm it ranged between 1.5% and 3.5% in pine forest and Khloo Paiung in August and June respectively.

In the second year (2003) at surface soil layer (0-10cm), potassium ranged between 2.25% and 4.1% in Khloo Langdoh and pine forest in February and December respectively. At sub surface soil layer (10-20cm) it ranged between 1.75% and 3.5% in Khloo Langdoh and pine forest in August and October and June respectively. At 20-30cm it ranged between 1.75% and 3.25% in Khloo Paiung and pine forest in December in both the cases (Fig. 3.3.6).

The analysis of variance (ANOVA) showed a significance variation at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm in Khloo Paiung and Khloo Langdoh and at 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in pine forest (Tables 6.1, 6.2 and 6.3).

In Khloo Paiung, the correlation coefficient values of potassium showed a positive correlation with total nitrogen, available phosphorus, organic carbon and microbial biomass carbon (Table 6.5). In Khloo Langdoh, the correlation coefficient values of potassium showed a positive correlation with available phosphorus, organic carbon, microbial biomass carbon and moisture content (Table 6.6). In pine forest, the correlation coefficient values of potassium showed a positive correlation with moisture content only (Table 6.7)

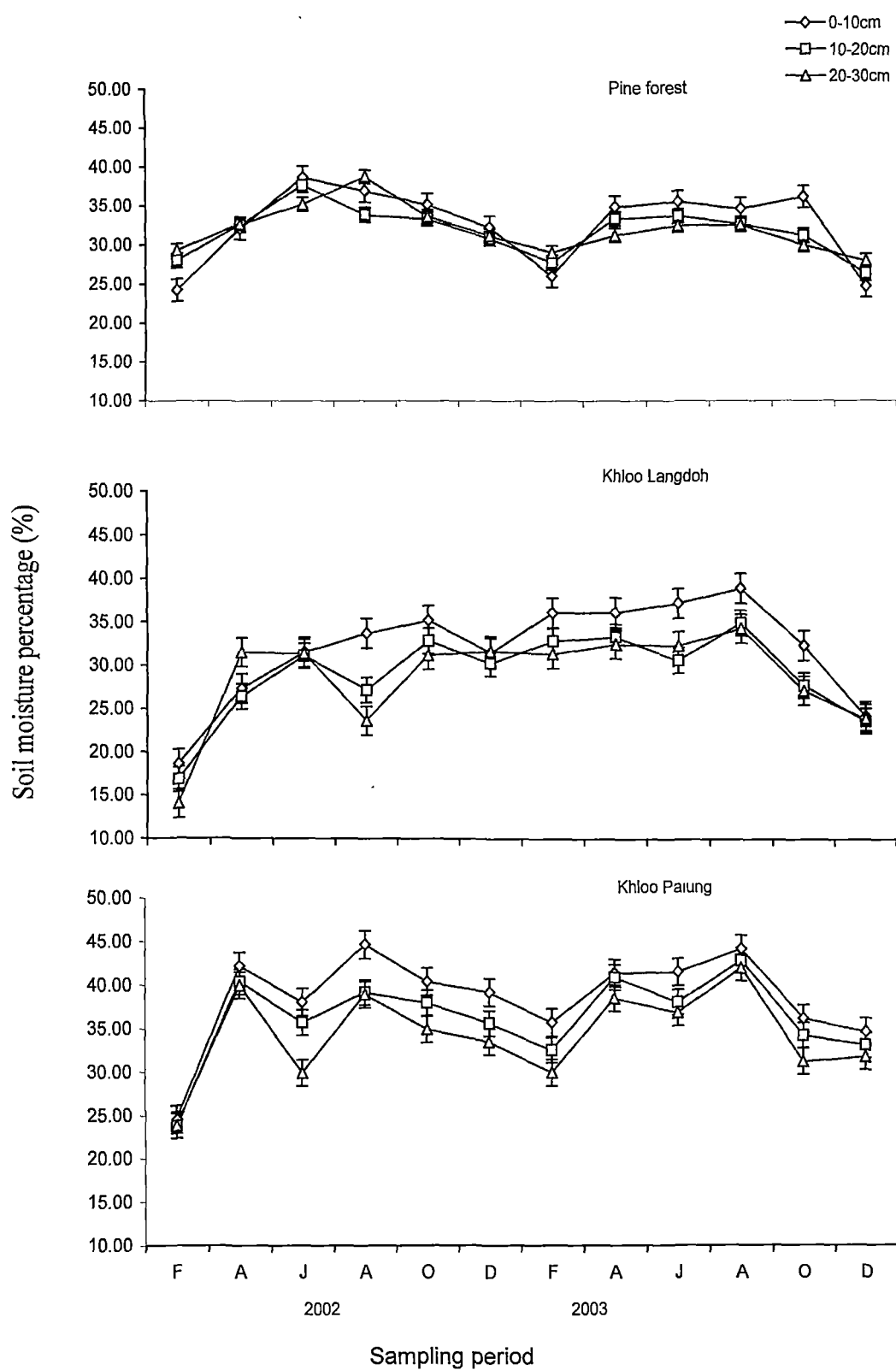


Fig 3.3.1. Bimonthly variation of moisture content in two Sacred Groves and Pine forest at 0-10cm, 10-20cm & 20-30cm depths.

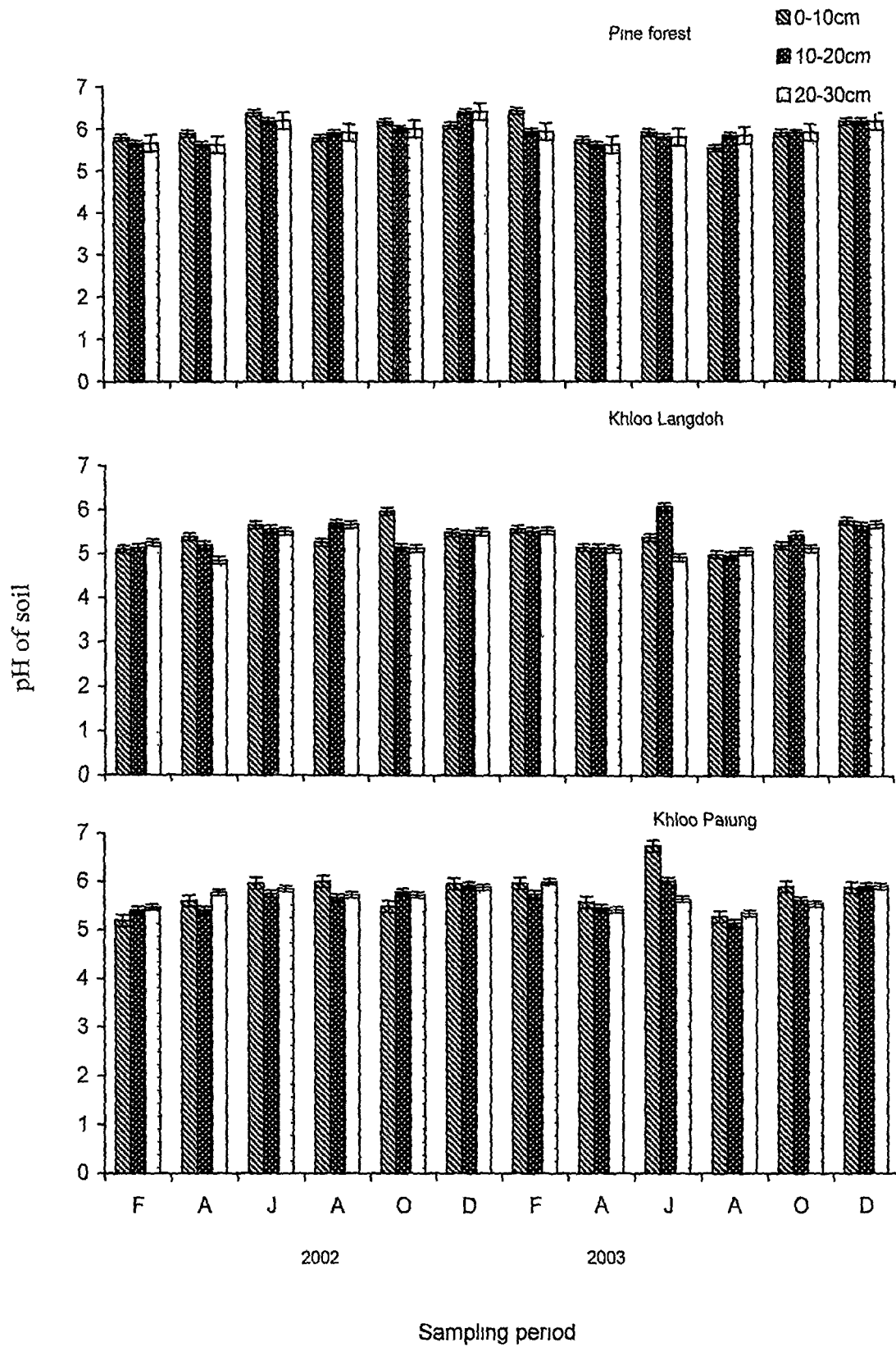


Fig 3 3 2 Bimonthly variation of pH in two Sacred Groves and Pine forest at 0-10 cm, 10-20 cm and 20-30 cm depths

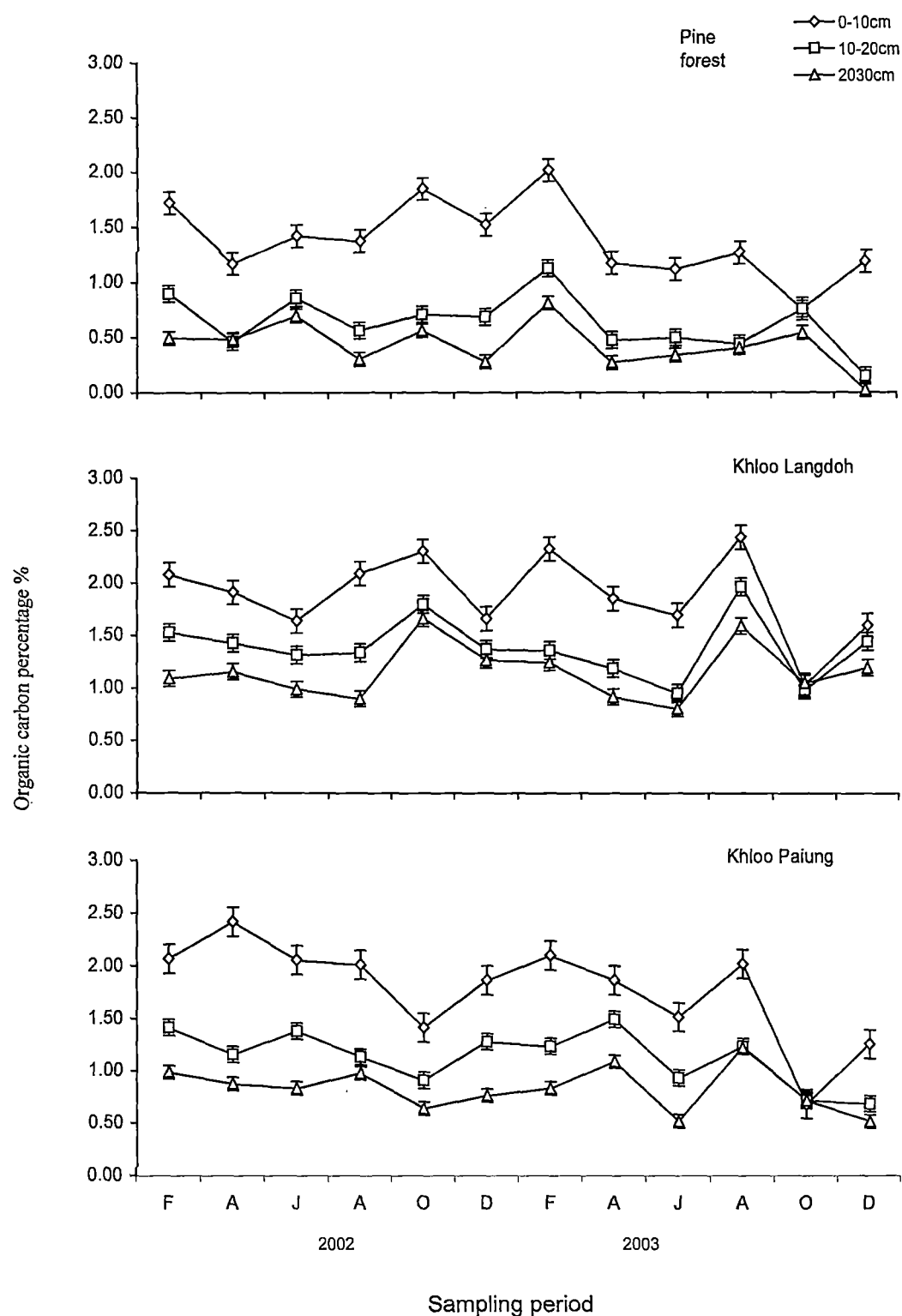


Fig: 3.3.3. Bimonthly variation of Organic carbon (%) in two Sacred Groves and Pine forest at 0-10 cm, 10-20 cm and 20-30 cm depths.

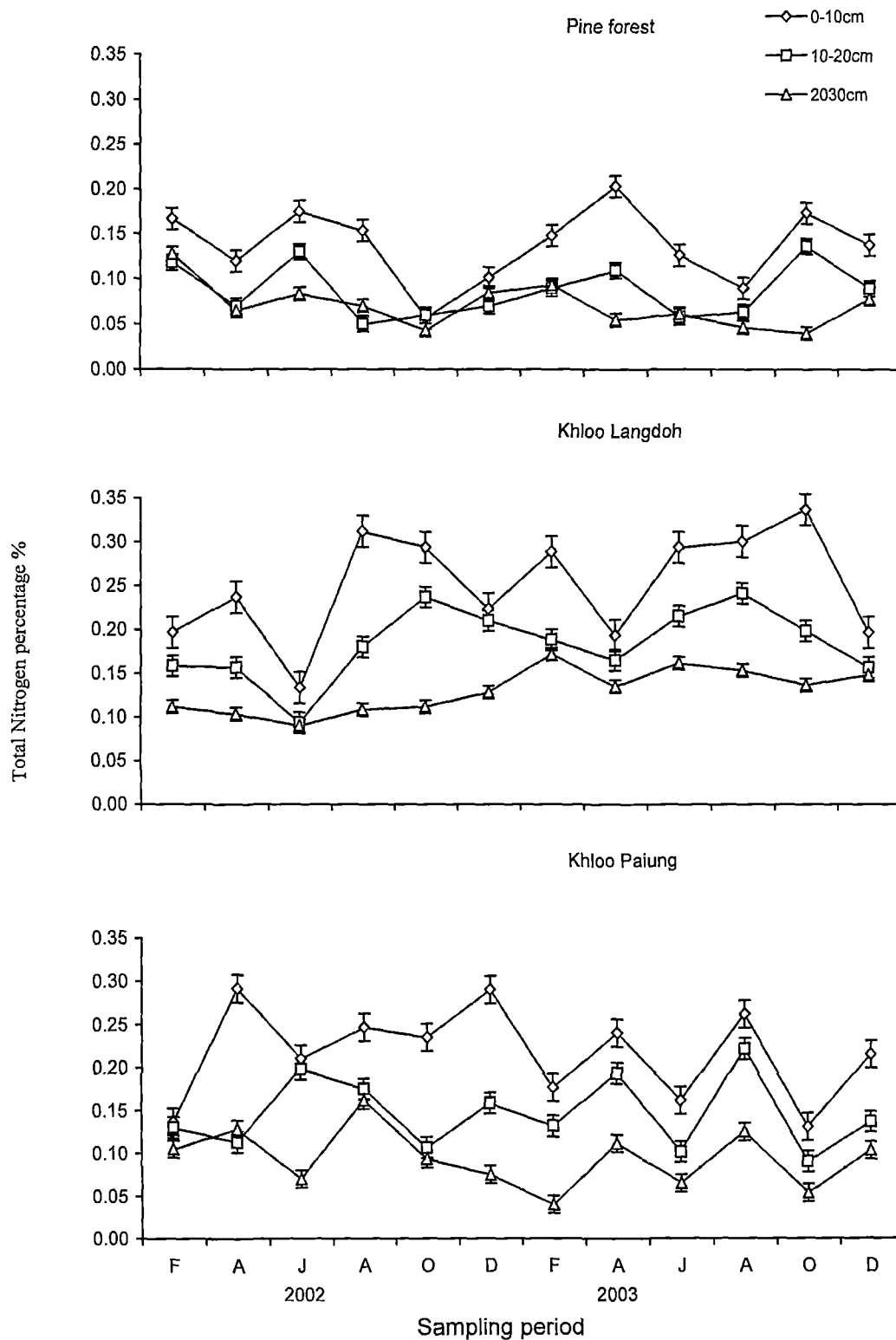


Fig: 3.3.4. Bimonthly variation of Nitrogen in two Sacred Groves and Pine forest at 0-10 cm, 10-20 cm and 20-30 cm depths.

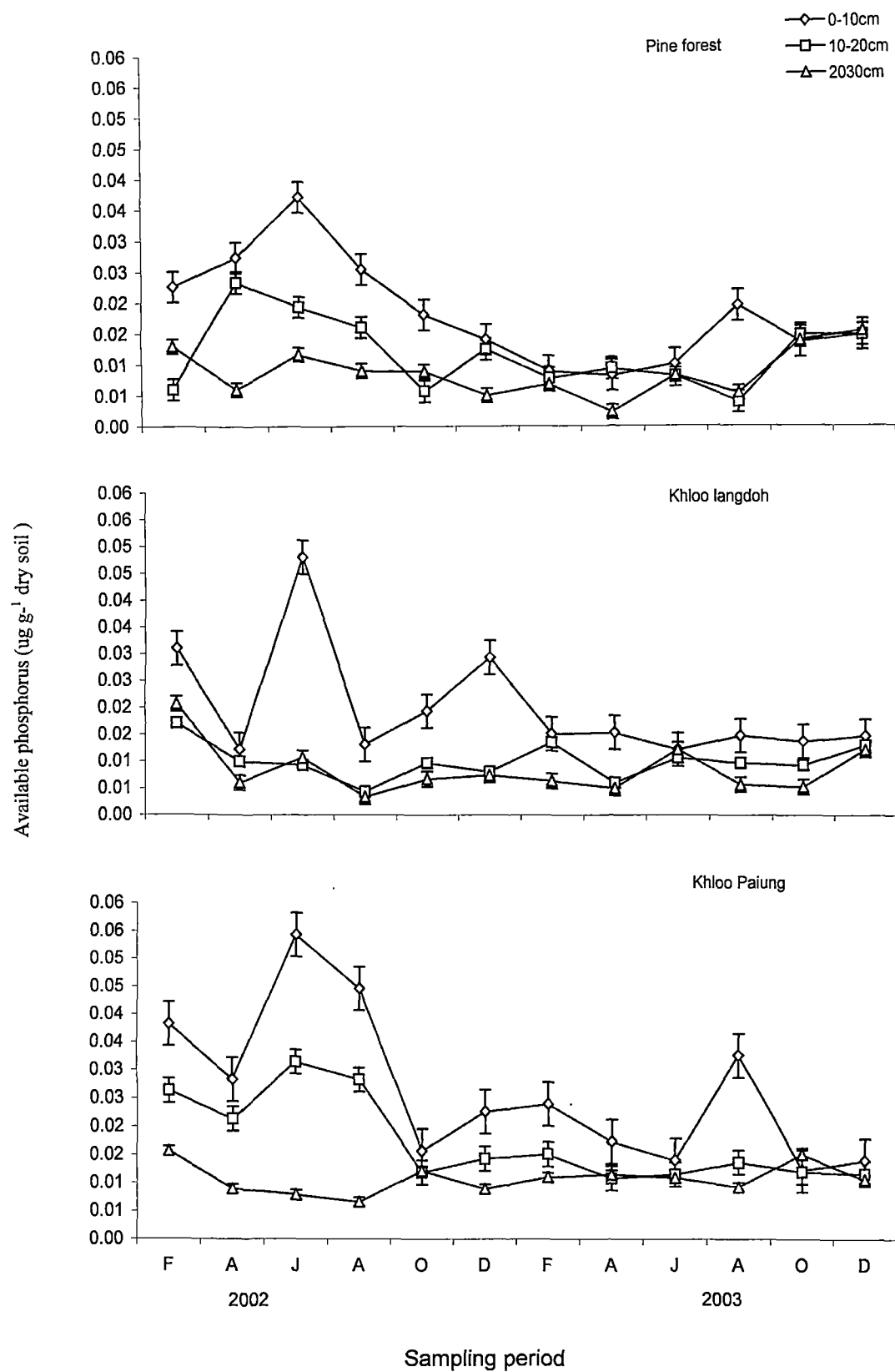


Fig: 3.3.5. Bimonthly variation of available phosphorus in two Sacred Groves and Pine forest at 0-10 cm, 10-20 cm and 20-30 cm depths.

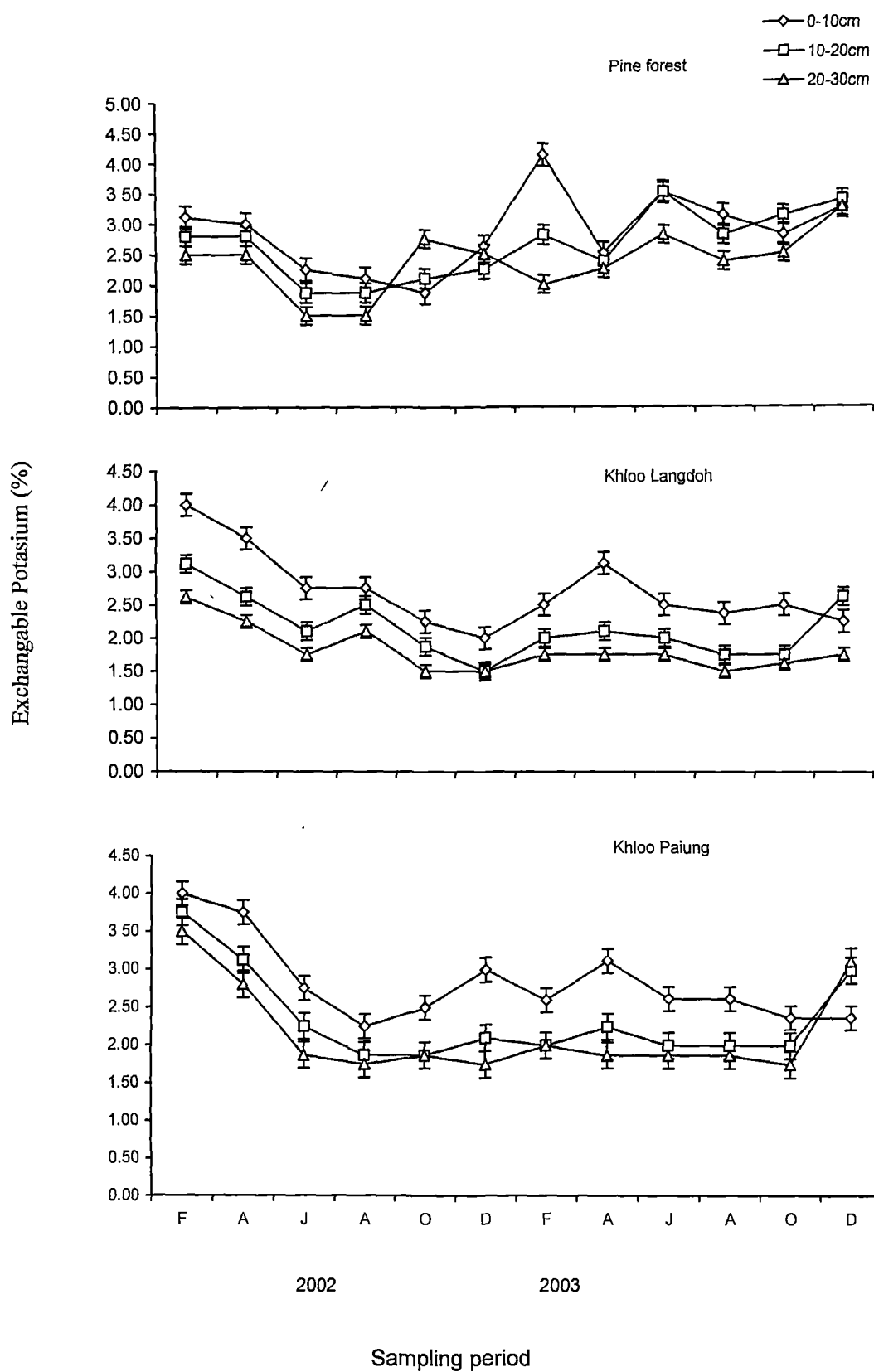


Fig: 3.3.6. Bimonthly variation of Exchangeable Potassium in two Sacred Groves and Pine forest at 0-10 cm, 10-20 cm and 20-30 cm depths

3.4. DISCUSSION

3.4.1. Soil moisture content

The high moisture content during the raining season and low moisture content during the winter season was mainly due to high rainfall during the raining season and low rainfall during winter season. Maximum moisture content at the surface soil layer could be due to greater accumulation of litter on the forest floor (Maithani, 1996; Singh, 2002). With increasing depth the accumulation of litter decreases as a result moisture content also decreases.

3.4.2. Soil pH

Soil pH is more or less slightly acidic in nature in all the three forest stands except that it tends to be more in some months in the pine forest. This is probably due to the presence of *Pinus* needles which are acid forming organic matter in the soil. The lack of significant correlations of pH with the various parameters could mean that a combination of factors is involved in influencing the soil pH.

3.4.3. Soil organic carbon

The higher organic carbon content on the surface soil layer in the two sacred groves may be due to the accumulation of organic matter on the forest floor after decomposition of litters (Brown *et al.*, 1994; Singh *et al.*, 1995). The presence of large amount of dead root material at the soil surface layer has greatly boosted the population of microorganisms. As a result microbial activity is high. The positive correlation coefficient of soil organic carbon with

fungus population and bacterial population showed that these microorganisms played an important role in the accumulation of soil organic carbon in the soil.

3.4.4. Total nitrogen

The increased percentage of total nitrogen in the two sacred groves is due to thick canopy of the groves which prevent nitrogen from being washed away during rain. Increased percentage during December in the first year indicated nutrient immobilization. During the study period, total nitrogen was found to be high at the surface soil layer than at the sub surface layer probably soil organic matter is more in the surface soil layer (Tate, 1987; Das *et al.*, 1997). Soil organic matter (SOM), especially humic substances, acts as a storehouse and supplier of nitrogen for plant roots and microorganisms. Almost 95% of total soil nitrogen is closely associated with SOM.

3.4.5. Available phosphorus

Available phosphorus is higher during summer and lower in winter, whereas phosphatase activity showed the reverse trend. The temporal variation of available phosphorus content in the soils has been found elsewhere. This result do not agree with the concept (Scott and Cullen, 1965) that available phosphorus builds up in the soil during periods of slow plant growth (i.e. in winter) rather that the contents build up concurrently with increase of plant growth during spring and summer as temperature increases (Sounders and Metson, 1971). On the other hand, in some cases, phosphatase activity tended to be high during winter months while available phosphorus showed a marked decrease. The reason for variability in the

phosphorus distribution in soil profile is based on its intricate chemical behavior. Tiessen *et al.* (1984) reported that the role of phosphorus in the functioning of forest ecosystems is, however, severely hampered by difficulties in identifying and quantifying available P in forest soils as phosphorus occurs in soil both in organic and inorganic forms.

3.4.6. Potassium

Low content of exchangeable potassium in the soil during rainy season could be attributed to the potassium itself, being a labile component of the soil, it could be washed easily from the soil during rainy season, or it could be easily leached down to the deeper layers of the soil (Tukey, 1970 and Uma Shankar *et al.*, 1991). Moisture content of the soil was also found to be directly related to the availability of potassium (Kuchenbuch *et al.*, 1986). While during winter season it can remain in the soil. Decline in exchangeable potassium could be seen with soil depth during rainy season and this could be due to unfavourable condition for the microbial activity (Tiwari *et al.*, 1988).

CHAPTER 4

ESTIMATION OF SOIL MICROBIAL BIOMASS C (C_{mic}) IN TWO SACRED GROVES AND PINE FOREST

4.1. Introduction

Microbial biomass is the characteristics of microorganisms, which participate in the biochemical cycles and are the live part of soil organic matter (Cengel, 1990; Srivastava, 1992). Microbial biomass which represents an important labile pool of nutrients in soil (Henrot and Robertson 1994) plays a significant role in nutrient transformation and conservation processes in grassland, forest and cropland ecosystems (Sarathchandra *et al.*, 1984; Singh *et al.*, 1989; Bolton *et al.*, 1993) in both tropical and temperate climates. The activity of microbial biomass is commonly used to characterize the microbiological status of soil (Nannipieri *et al.*, 1990, Gil-Sotres *et al.*, 2005). Measurements of soil microbial biomass have been used in studies of the flow of carbon, cycling of nutrients and plant productivity in a variety of terrestrial ecosystems (Voroney *et al.*, 1993). Recognition of the importance of soil microorganisms in the functioning of ecosystem has led to an increased interest in measuring the nutrients held in soil biomass (Martikainen and Palojarvi, 1990).

Microbial biomass is a key component of soils since it defines the functional component of the microbiota primarily responsible for decompositions, soil organic matter turn over and nutrient transformations (Smith and Paul 1990, Witter, 1996). The microbial biomass carbon has been

used as an approach to evaluate soil quality Gil-Sotres *et al.* (2005). The size of the microbial biomass in soils is related to factors such as annual carbon input, agricultural practices (Anderson and Domsch, 1989) and successional state of the ecosystems (Insan and Domsch, 1988).

Many factors such as temperature, moisture content, clay content and pH are known to affect microbial biomass in soil (Gestel *et al.*, 1993, Nicrojardot *et al.*, 1994). The Microbial biomass content of a soil depends on the quantity, quality and distribution of the carbon input factors that vary with time and depth (Kaiser and Heinemeyer, 1993). The soil microbial biomass constitutes a transformation matrix for all the natural organic materials in the soil and acts as a labile reservoir of plant-available nutrients (Jenkinson and Ladd, 1981). Estimation of soil microbial biomass is now frequently made because of the importance of soil organisms in nutrient cycling and their role as a source and sink of plant nutrients (Smith and Paul, 1990). Thus the study of microbial communities and biomass in forest soil may give insight into the role of microbes in restoring soil fertility.

4.2. Methodology

4.2.1. Estimation of microbial biomass carbon (C_{mic})

The soil microbial biomass carbon was estimated by Chloroform Fumigation Incubation (FI) method of Anderson and Ingram (1993). The soil was sieved through 2 mm mesh sieve to remove stones, coarse roots and all visible litters. 10 g of each sample was taken in a beaker and was placed in a vacuum desiccator containing 30 ml of alcohol free chloroform in a shallow

dish. The lid was closed and sealed and the vacuum was used till the last trace of chloroform evaporated and thereafter the desiccator was kept in the dark for 5 days at 25⁰ C. Next, weighed another 10 g of each sample for unfumigated extraction (ct₂). The sample was then kept in a watertight extraction bottle (125 ml) and extracted directly without fumigation with 50 ml of 0.5 M K₂SO₄ and was shaken for 30 minutes. After 5 days the fumigated soil (ct₁) sample was extracted like the unfumigated soil sample. The extracted soil was then filtered through Whatman filter paper No.42. To a 4 ml filtrate, 1 ml of 0.0667 M potassium dichromate and 5 ml of concentrated sulphuric acid were added. The mixture sample was then preheated at 150⁰C for 30 minutes. Two blanks were prepared i.e. one preheated at 150⁰C for 30 minutes and the other without heating. The digested sample was then transferred to a 100 ml conical flask and to it 0.3 ml of indicator solution (O-phenanthroline monohydrate) was added. The sample was then titrated with acidified ferrous ammonium sulphate solution. The end point was a colour change from green/violet to red. Three replicates were maintained in each case. For blank, 4 ml of 0.5 M K₂SO₄ solution was added in place of sample filtrate solution.

The microbial biomass C was calculated as follows:

$$\text{Organic C (\%)} = \{(A \times M \times 0.003)/g\} \times (E/S) \times 100$$

Where, *M* = Molarity of ferrous ammonium sulphate (= 0.033M)

$$A = (MI_{HB} - MI_{sample}) \times \{(MI_{UB} - MI_{HB})/MI_{UB}\} + (MI_{HB} - MI_{sample})$$

G = Dry soil mass (g)

E = Extraction volume (ml)

S = Digest sample volume (ml)

$$\text{Microbial biomass C} = (\text{Extracted } ct_1 - \text{Extracted } ct_2) \times 2.46$$

Indicator solution:

1.485 g of O-phenanthroline monohydrate was mixed with 0.669 g of ferrous ammonium sulfate hexahydrate and to this 100 ml of distilled water was added.

4.3. Results

Microbial Biomass Carbon (C_{mic})

Soil microbial carbon showed variation in all the three forest stands. The two sacred groves showed much more soil microbial biomass carbon (C_{mic}) as compared to the pine forest. In all the three cases, the soil microbial biomass carbon (C_{mic}) declined from the surface (0-10 cm) to sub surface (10-20 cm and 20-30 cm). Microbial biomass carbon was high in April and December 2002 and April 2003 in Khloo Paiung and in June and December 2002 and April 2003 in Khloo Langdoh, while in pine forest it was high in June 2002 and February 2003. Low microbial biomass carbon was observed in August 2002 and August 2003 in Khloo Paiung, April 2002 and October 2003 in Khloo Langdoh and April 2002 and December 2003 in Pine forest. So mostly it is high in warm and low in winter season except December 2002 (Fig 4.3.1).

The one way analysis of variance (ANOVA) showed significant variation of microbial biomass carbon activity at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in all the forest stands (Tables 6.1, 6.2 and 6.3).

In Khloo paiung C_{mic} was positively correlated with total nitrogen, potassium, organic carbon and urease (Table 6.5). In Khloo Langdoh C_{mic} was positively correlated with available phosphorus, potassium, organic carbon, dehydrogenase, bacterial and fungal population (Table 6.6). In Pine forest C_{mic} was positively correlated with total nitrogen, available phosphorus, organic carbon, dehydrogenase, bacterial and fungal population (Table 6.7).

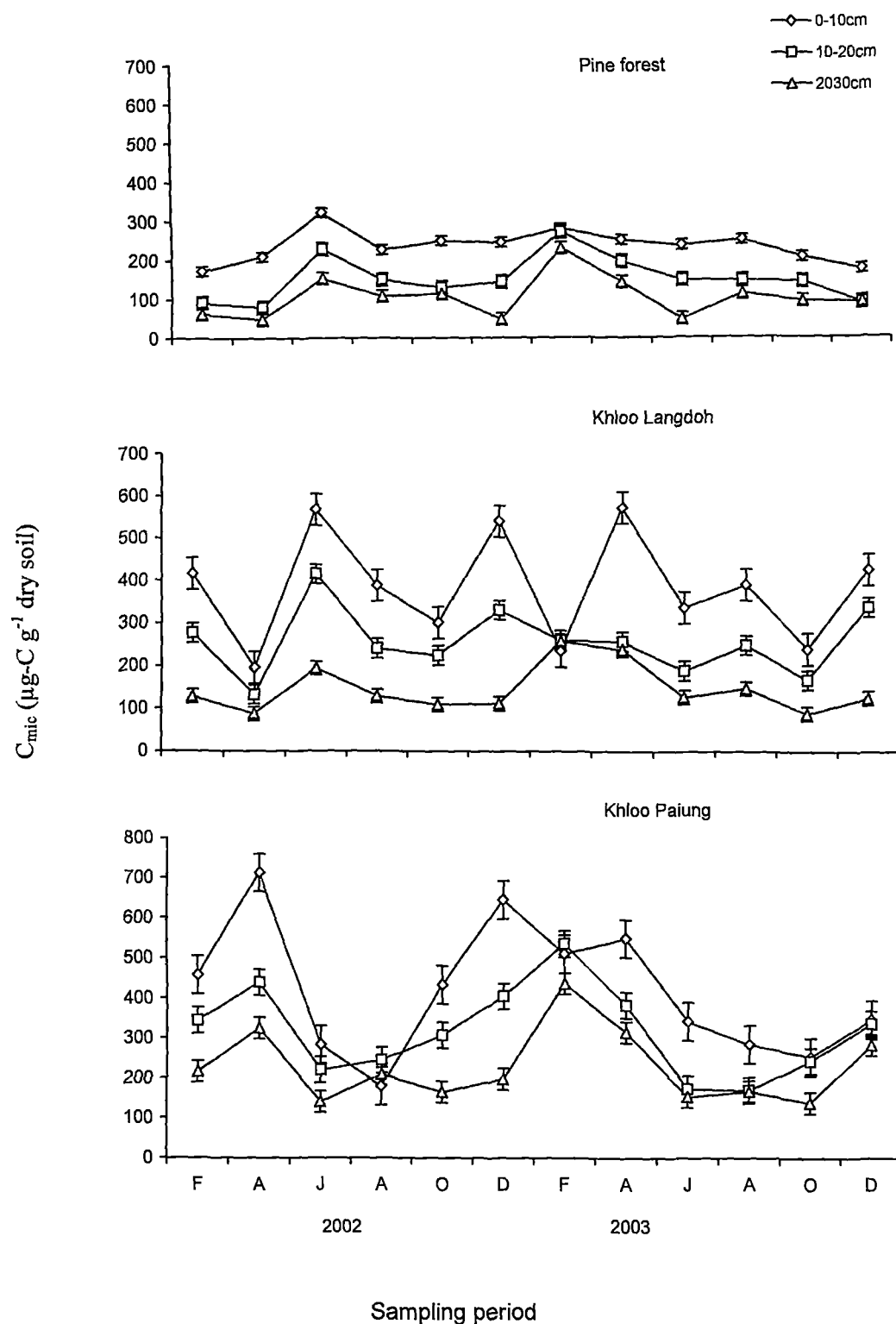


Fig. 4.3.1 Bimonthly variation of microbial biomass carbon (C_{mic}) at three different depths (0-10cm, 10-20cm and 20-30cm) in two Sacred Groves and Pine forest.

4.4. Discussion

Microbial biomass carbon is more in the surface layer (0-10 cm) than in the subsurface layer (10-20 cm and 20-30 cm). The increase in the microbial biomass carbon in the surface layer (0-10 cm) than in the subsurface layer (10-20 cm and 20-30 cm) in all the three forests stand may be attributed to the increase in organic matter and nutrients (Ross *et al.*, 1982, Acea and Carballas, 1996; Jha *et al.*, 1992; Kaiser and Hein Meyer, 1993). The increased could also be due to the increase in the soil fungal and bacterial populations and as well as due to the concentration of plant residues near the surface. The low microbial biomass carbon in the subsurface layer reflects the decreasing percentage of fresh plant material in the soil organic matter as a result of the decreasing carbon input rate of roots (Kner Meyer *et al.*, 1996).

In both the sacred groves the microbial biomass is high during spring and summer with the most active growth of plants and microbial activity along with warm conditions and favorable moisture which favour the growth of the microorganisms (Gracia *et al.*, 1997, 2002). Lovell *et al.*, (1994) also supported the finding that microbial biomass carbon increase in spring which are thought to result from increased availability of root exudates as root growth and turn over increases in spring (Lynch and Panting, 1980). High microbial biomass carbon was seen during December in the first year of study. This was attributed to greater immobilization when the activity is low. Increased microbial biomass carbon during winter and rainy season indicated a period of rapid mineralization in soil. Seasonal patterns of changes in

biomass carbon and nitrogen have also been reported by Sarathchandra *et al.*, (1988) and Briston and Jawis (1991). A marked seasonal cycle of microbiological biomass has been reported for both tropical and temperate forest soil (Singh *et al.*, 1989, Diaz-Ravina *et al.*, 1995). Diaz-Ravina *et al.* (1995) have highlighted the influence of land use and soil physio-chemical properties on soil microbial biomass.

The positive correlation of microbial biomass carbon with the enzyme activity in all the three forest stand is also supported by Domsch *et al.* (1980) and Frankenberg and Dick (1983). Microbial biomass correlates significantly with moisture and organic carbon. Increased moisture enhanced the availability of organic carbon which is responsible for an increased microbial activity (McGill *et al.*, 1986; Anderson and Domsch, 1989). Microbial biomass carbon reflects the long term amount of C input into the soil (McGill *et al.*, 1986; Anderson and Domsh, 1986).

The analysis of variance showed significance declined ($P < 0.01$) of microbial biomass carbon from surface layer to sub surface layer as found by Lavahun *et al.*, (1996). The observation that the microbial biomass carbon declines with depth was similarly reported by Kaiser and Hein Meyer (1993). Santruckova (1991) reported that the microbial biomass depends positively on the soil organic carbon contents and on soil moisture and it can have a direct effect on microbial biomass (Scott-Denton *et al.*, 2003).

CHAPTER 5

ESTIMATION OF MICROBIAL ENZYME ACTIVITIES (DEHYDROGENASE PHOSPHATASE AND UREASE) IN TWO SACRED GROVES AND PINE FOREST

5.1. Introduction

Dehydrogenase, urease and phosphatase are recognized as very important soil enzymes. Dehydrogenase has been widely used to measure catabolic activities in soil, which is largely confined with microbial activity (Skujins 1976). Measurement of dehydrogenase activity provides an index of the catabolic activity of soil. The urease enzyme is responsible for the breakdown of urea into carbon dioxide and ammonia. Phosphatase mediates the release of inorganic phosphorus from organically bound phosphorus returned to soil as litter and organic debris. Urease and phosphatase are involved in transformations of nitrogen and phosphorus.

Even though it has been accepted that enzymes in soils originate from animal, plant and microorganisms, however the presence of enzymes in soils derived directly or specifically from animal and plant sources has yet to be demonstrated conclusively. As microorganisms are important source of soil enzymes, the activity of these enzymes have often been used as an index of microbial activity. Changes in enzyme and microbial activities could alter the availability of nutrients for plant uptake (Dick *et al.*, 1988 a, b) and these changes are potential sensitive indicators of soil quality (Skujins, 1978; Dick 1994). Soil enzyme activity is believed to be sensitive to population and has

been proposed as an index of soil degradation (Trasar- Cepeda *et al.*, 2000; Gianfreda *et al.*, 2005)

5.2. Methodology

5.2.1. Estimation of Dehydrogenase activity

2-3-5-Triphenyl Tetrazolium Chloride (TTC) reduction technique (Casida, 1977) was used for the estimation of dehydrogenase activity in soil. One g of fresh soil was taken in a test tube. The soil was then mixed with 0.1 g of calcium carbonate (CaCO_3) and 1 ml of 1% TTC solution. The mixture was then shaken and plugged with a rubber stopper and incubated at 30°C for 24 hours in an incubator. Three replicates were maintained in each case. The resulting slurry was transferred on Whatman filter paper No.1 and extracted with successive aliquots of concentrated methanol. The volume of the filtrate was made to 50 ml by adding methanol. The optical density of the filtrate was read at 485 nm on Hitachi Spectrophotometer (220), using methanol extract as a blank. The activity was representing in terms of concentration of Formazan, which was calculated by a standard curve of triphenyl formazan in methanol. Dehydrogenase activity per gram dry soil was expressed in terms of milligram formazan per gram dry soil per hour.

5.2.2. Estimation of Urease activity

The activity of urease was measured by the method of McGarity and Myers (1967). One g fresh soil was kept in 100 ml volumetric flask and to it 1ml of toluene was added. It was then allowed to stand for 15 minutes to permit the complete penetration of toluene in to the soil. Thereafter, 10 ml of

buffer (pH 7) solution and 5 ml of 10% Urea solution were added. The flask was shaken and incubated at 37°C for 3 hours in an incubator. A control solution is prepared by adding 10 ml of distilled water instead of urea solution. After incubation, the volume was made up to 100 ml by adding distilled water. The content in the flask was mixed thoroughly and was filtered through Whatman filter paper No. 5. Indophenol blue method was adopted for the measurement of ammonia released as a result of urease activity. 0.5 ml of filtrate was taken in a 25 ml volumetric flask and to it 5 ml of distilled water was added. The mixture in the flask was treated with 2 ml of phenolate solution and 1.5 ml of sodium hypochloride solution containing 5% of active chlorine. The final volume was made up to 25 ml by adding distilled water. The optical density was read in a Hitachi (220) spectrophotometer at 630 nm. The amount of NH_4^+ -N released was calculated by a reference-calibrated curve and was expressed as NH_4^+ - N mg per gram dry soil per three hours.

Preparation of Phenolate solution

20 ml of phenol solution + 20 ml of caustic soda solution were diluted to 100 ml with distilled water.

Phenol solution

62.5g of phenol was dissolved in minimum volume of methanol denatured alcohol to this 18.5 ml of acetone was added and this mixture was made up to 100 ml with alcohol.

Caustic soda solution

27g of sodium hydroxide were dissolved in 100 ml of distilled water. Both the solutions were kept in a freeze.

5.2.3. Estimation of Phosphatase activity

Phosphatase activity was measured by the method of Tabatabai and Bremner (1969). 0.1 g of air-dried soil was taken in to a 50 ml conical flask. Then 4 ml of modified universal buffer (pH 6.5), 0.25 ml of toluene and 1 ml of 0.115 M p-nitrophenyl phosphate (PNP) solution was added to the flask (Skujins, 1985). The flask was swirled for few seconds and then incubated at 37⁰ C for one hour in an incubator. After incubation, 1 ml of 0.5 M calcium chloride and 4 ml of 0.5 M sodium hydroxide was added to the mixture. The soil suspension was filtered through Whatman filter paper No. 1. The optical density of the filtrate was measured at 430 nm in Hitachi (220) spectrophotometer. Blank was maintained similarly without soil. The phosphatase activity in terms of concentration of p-nitrophenyl in each sample was calculated by a standard curve of p-nitrophenol in water and was expressed as mole of p-nitrophenol released per gram dry soil per hour.

5.3. Results

5.3.1. Dehydrogenase activity

Dehydrogenase activity in the first year (2002) was maximum during rainy season (June and August) in Khloo Paiung and Pine. In the second year (2003) it was high in August in all the forest stands. Minimum activity in

Deceber and February in both the years. Dehydrogenase activity decreased rapidly with increasing depth (from 0-10cm up to 10-20cm and 20-30cm) [Fig. 5.3.1].

Dehydrogenase activity showed positive correlation with total nitrogen, organic carbon, soil moisture bacterial population and fungal population in Khloo Paiung (Table 6.5). In Khloo Langdoh, the dehydrogenase activity showed positive correlation with total nitrogen, C_{mic} , urease, phosphatase, and bacterial population (Table 6.6). In Pine forest also, a positive correlation with organic carbon, C_{mic} , microbial carbon and fungal population was seen (Table 6.7).

The one way analysis of variance (ANOVA) showed significant variation of dehydrogenase activity at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in all the forest stands (Tables 6.1, 6.2 and 6.3).

5.3.2. Phosphatase activity

Phosphatase activity was maximum in June 2002 and October 2003 and minimum in December during the study period. In all the three forest stands, phosphatase activity gradually declined from the surface soil layer (0-10cm) to the sub-surface layer (10-20cm and 20-30cm). The phosphatase activities in both the two sacred groves were more than that of the Pine forest (Fig 5.3.2).

The one way analysis of variance (ANOVA) showed significant variation of phosphatase activity at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in Khloo Paiung, at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm in Khloo Langdoh and at 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in pine forest (Tables 6.1, 6.2 and 6.3).

Phosphatase activity showed positive correlation with total nitrogen, available phosphorus, organic carbon, urease, bacterial population in Khloo Paiung (Table 6.5). In Khloo Langdoh, phosphatase activity showed positive correlation with total nitrogen, urease, dehydrogenase (Table 6.6). In Pine Forest phosphatase activity showed positive correlation only with bacterial and fungal population (Table 6.7).

5.3.3. Urease activity

Urease activity was maximum in June 2002 and October 2003 and minimum in February and December 2002 whereas in the second year there is an increased in urease activity in April and December 2003.

Urease activity is more at the surface soil layer (0-10cm) than at the subsurface soil layer (10-20cm and 20-30cm) Fig 5.3.3.

The one way analysis of variance (ANOVA) showed insignificant variation of urease activity at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in Khloo Paiung and pine

forest at 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm in Khloo Langdoh (Tables 6.1, 6.2 and 6.3).

Urease activity was positively correlated with C_{mic} , available phosphorus and fungal population in Khloo Paiung (Table 6.5). In Khloo Langdoh, urease activity was positively correlated with dehydrogenase, available phosphorus and bacterial population (Table 6.6). In Pine forest however, urease activity was positively correlated with bacterial population only (Table 6.7).

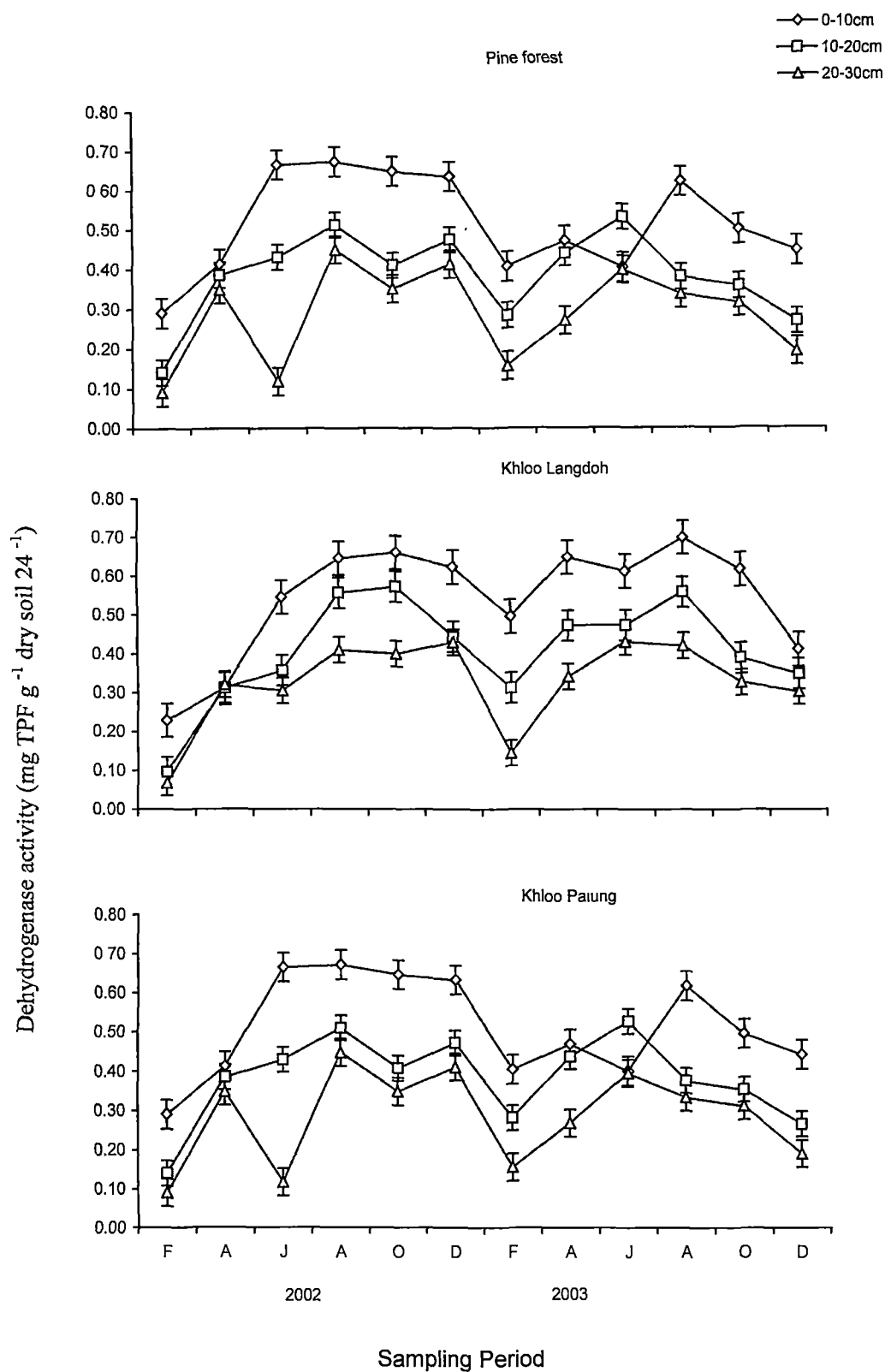


Fig. 5.3.1. Bi monthly variation in dehydrogenase activity in the two Sacred Groves and Pine forest at 0-10cm, 10-20cm and 20-30cm depths.

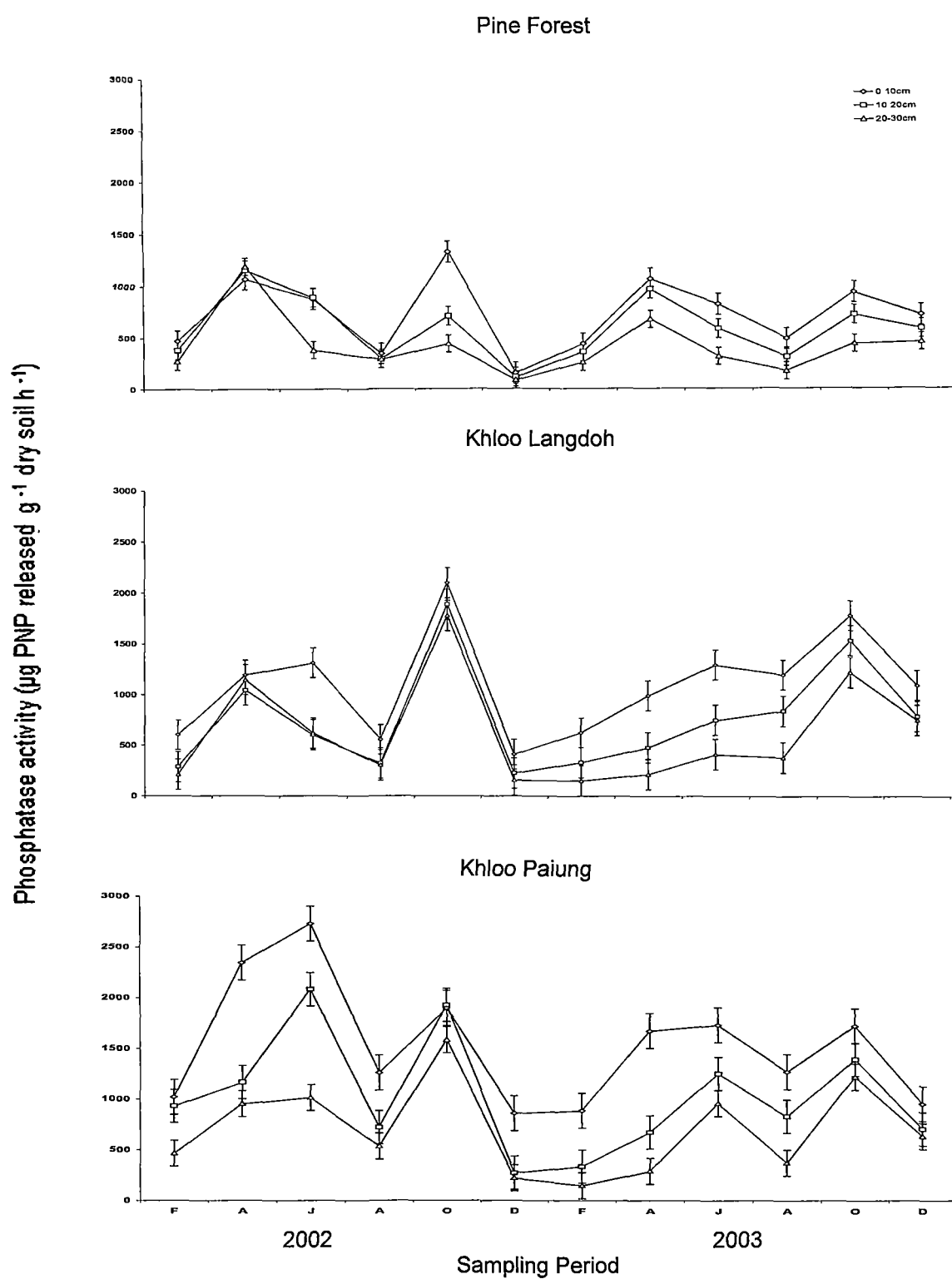


Fig: 5.3.2. Bimonthly variation of phosphatase activity in the two Sacred Groves and Pine forest at 0-10 cm, 10-20 cm and 20-30 cm depths.

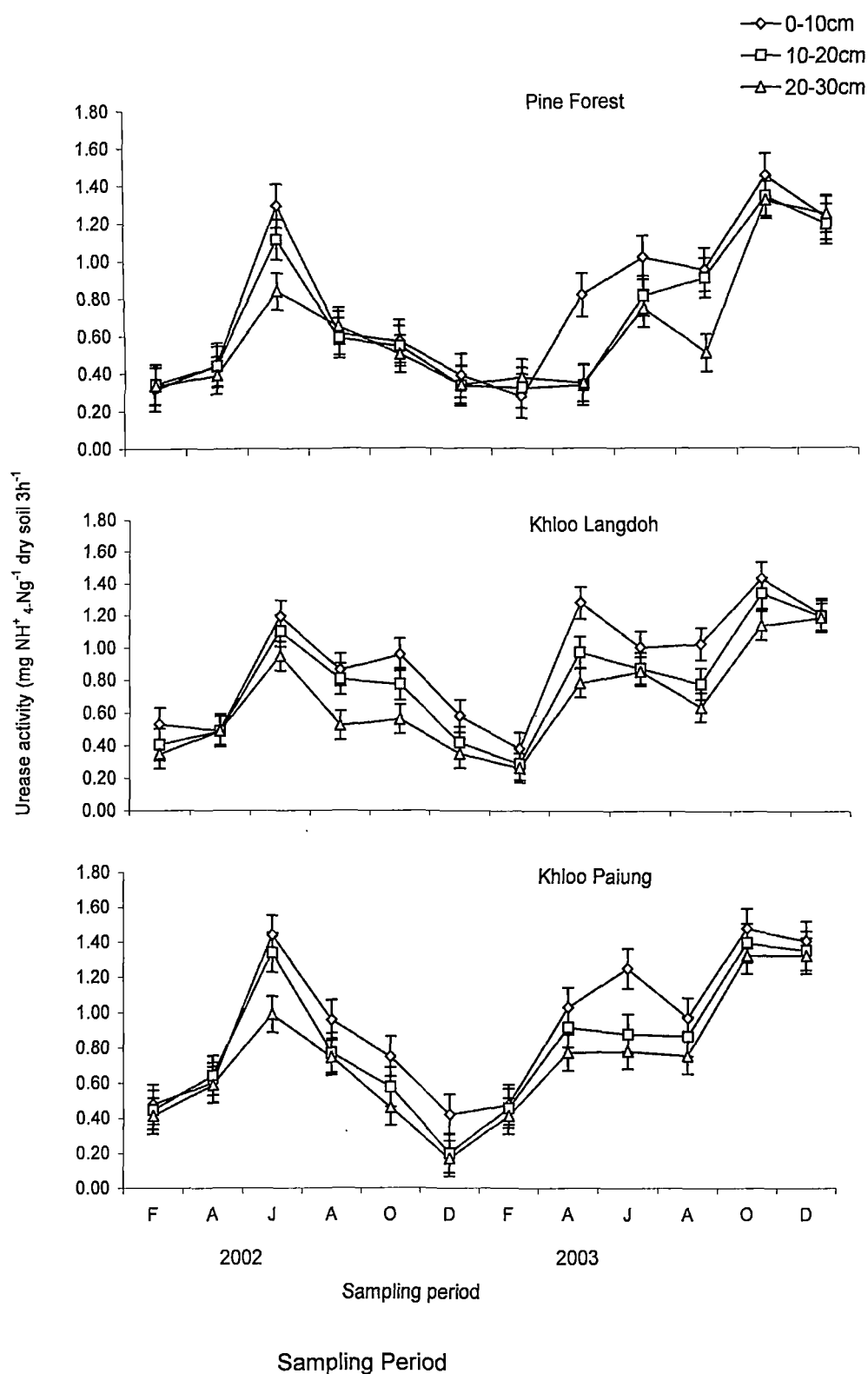


Fig: 5.3.3. Bimonthly variation of urease activity in the two Sacred Groves and Pine forest at 0-10 cm, 10 20 cm and 20-30 cm depths

5.4. Discussion

5.4.1. Dehydrogenase activity

Dehydrogenase activity was high during rainy and low during winter which indicated that rainy season is mostly a favourable season for microbial activities. This is also related to the moisture content of the soil (Baruah and Mishra, 1984; Tiwari *et al.*, 1987). During winter, reduction of soil moisture caused dryness of the soil which is unfavourable for the growth of microorganisms. An increase in soil moisture enhanced the availability of organic carbon which is responsible for the increased microbial activity as indicated by a positive correlation between organic carbon and dehydrogenase activity (Shukla *et al.*, 1989 and Rao *et al.*, 1995). The strong relationship between dehydrogenase and microbial biomass C indicates that dehydrogenase activity in these soils may be a good indicator of microbial biomass and activity (Bolton *et al.*, 1993).

5.4.2. Phosphatase activity

Phosphatase in the soil mainly sourced from microbial sources, plants and animals. Microbial activity was at a maximum in rainy season because of the favourable condition for all the activities and was at a minimum in December (winter) where root growth is normally low during the winter months. The less activity in winter months was due to reduced amount of organic carbon and low moisture content compared to rainy season (Dormaar *et al.*, 1984 and Rao *et al.*, 1995). Seasonal pattern of phosphatase activity

seem to depend upon many factors such as aeration, soil moisture content, vegetation and microflora (Nannipieri *et al.*, 1979; Chhonkar and Tarafdar, 1984). Soil phosphatase activity is generally directly related to soil organic carbon content in soil profiles (Tiwari, 1988) as indicated by the positive correlation of phosphatase activity with organic carbon.

This investigation also corroborates the findings of Singh (2002) who reported that phosphatase activity like most other enzyme activities decreases with soil depth. The phosphatase activity was more in the surface soil layer than in the subsurface soil layer probably because of the presence of large amount of dead root material, which have also greatly boosted the population of micro organisms. These micro organisms have been implicated as possible major contributors of enzyme to soil (Speir, 1976). However in Khloo Langdoh, there is no positive correlation of phosphatase with that of bacterial and fungal populations. This suggested that enzymes in soils do not only originate from microbial sources, but also from animals and plant roots. The presence of plants positively affects enzyme activities as reported by Tadano *et al.* (1993). The lack of a significant correlation between phosphatase activity and bacterial and fungal population indicated that the other factors affect the level of enzyme activity in forest soils. Tiwari (1996) observed that generally the enzyme activities increased with increasing organic total nitrogen and total phosphorus contents of the soil. Positive relationships between enzyme activities and organic carbon and total nitrogen have been observed.

Vegetation plays a major role in litter input in the two sacred groves. The asymmetrical inputs of litter through soil profile due to the above ground litter incorporation in the soil surface together with a better soil aeration accounts for the higher soil enzyme activity in the surface layer (0-10cm) than in the subsurface soil layer (10-20cm and 20-30cm).

5.4.3. Urease activity

High urease activity observed during rainy season and low activity during winter was due to an increase in number of microorganisms (Stott and Hagedorn, 1980; Watanabe and Hayano, 1995). Baum *et al.* (2003) observed that enzyme activities can vary depending on the sampling date in zone with a seasonal climate.

Urease activity decreased through soil profile could also be due to organic carbon (Aon and Coloneri, 2001; Taylor *et al.*, 2002). Chen (2003) also reported that decreases in soil enzyme activities through soil profile have been observed in forests and agricultural soils due to organic inputs in the soil surface. While in winter there is low organic input, low temperature and low moisture content which reduced the microbial population. Skujins (1976) reported that urease activity generally correlates with organic matter due to its existence as a complex with organic constituents. It may be affected by temperature, soil factors, such as moisture content, phosphorus, organic matter and number of micro organisms (O'Toole *et al.*, 1985). Aon and Colaneri (2001) described strong relationships between organic carbon and total nitrogen with enzymatic activities.

CHAPTER 6

GENERAL DISCUSSION

Species diversity of fungi and bacteria were higher in sacred groves than in pine forest which can be attributed to the soil characteristics and nature of the forest. Higher amount of carbon, nitrogen etc suggests an increase in maturity of the plant community or stage of soil development (Vitousek and Reiners, 1975; Liu *et al.*, 2000) thereby supporting increased diversity of the soil microflora.

The number of fungi and bacteria were higher at surface soil layer (0-10cm) than at sub surface layer (10-20cm and 20-30cm). This was supported by Piriyaiprin *et al.* (2002) and Kayang (2006) that the number of microorganisms and their activities in the upper soil depth were higher than those of the lower. It is widely accepted that organic substances that are exuded by plant roots affect microorganisms in the soil surrounding the roots. Decline of fungi and bacteria with depth could be regarded as reduction to soil quality. The organic matter, microbial population, and all other microbial activity decreases with increasing depth. Reductions of both fungi and bacteria populations were a reflection of the nutrient status of the soil (Zvyagin et al., 1994). Warcup (1967) and Kayang (2006) reported that the number of fungal species is highest at the soil surface. Sacred groves forest soil at 0 –10cm depth has the greatest number of both fungi and bacteria count in all cases. This was supported by Piriyaiprin *et al.* (2002) and Oseni *et al.* (2007).

Similarity index of both fungi and bacteria in all the three forest stands showed that all the indices ranged between 0.44 - 0.58 for fungi and 0.8 - 1.0 for bacteria. This could be attributed to some disturbances which have been occurred due to human activities, as these sacred groves are situated near the residential areas. The dominance of fungi like *Aspergillus* sp, *Penicillium* sp, *Oidiodendron* sp and *Trichoderma* sp. and bacteria like *Microccus* sp, *Arthrobacter* sp and *Rhizobium* sp is in accord with observations by Bissett and Parkinson (1979) who pointed out that for a given community, one or a few species are numerically dominant.

The Shannon diversity index (Fig 6.1) of fungi and bacteria in the two sacred groves and pine forest showed that it was higher in the two sacred groves which may be contributed to difference in the vegetation and tree species which affect chemical and microbial properties of soil in a different extent (Priha *et al.*, 1999). ANOVA (Table 6.4) revealed significant differences in microbial abundances and other activities between the study sites which suggested that the physical, chemical and biological characteristics of a particular soil, as well as growing plants influence the number and activities of its various microbial components (Germida, 1993; Uckan and Okur, 2004).

There has been a seasonal fluctuation in the microbial community. Maximum population of fungi and bacteria are generally observed in summer and minimum in winter which could be attributed to the favourable soil moisture and organic matter content. Seasonality may influence the microbial biomass directly by inducing microbial community responses to soil moisture

and temperature (Anderson *et al.*, 2003). Seasons indirectly affect plant productivity and thus the seasonal pattern of organic matter release. In soils of temperate coniferous forest, bacterial and fungal biomass usually peak in spring and/or autumn but not in winter (Soderstrom, 1979; Clarholm and Roswall, 1980; Baath and Soderstrom, 1982; Wardle 1992). It is quite clear that the pattern of distribution of microorganisms is affected by many environmental factors (Rehder and Schafer, 1978).

The short term changes in environmental condition as it appears from the investigation might be major importance for the changes in the population of fungi and bacteria. Precipitation causes rapid changes in the soil environment. In addition to wetting of the soil, rainfall results in increased availability of nutrients in soil (Clarholm and Rosswall, 1980). Precipitation may show a better indicator of short term changes in the soil environment than soil moisture content at a specific date. Since the latter might be more seasonally dependent. As microbial population levels are generally correlated with temperature and moisture content of soils (Alexander, 1977, Schimel *et al.*, 1999). These populations are expected to change during the year with season and environment (Kieft *et al.*, 1998).

Soil moisture content was higher in rainy and low in winter which could be attributed to high and low rainfall respectively. High moisture content at the surface soil layer could be due to greater accumulation of litter and organic matter at the surface soil layer than the subsurface soil layer (Maithani *et al.*, 1996). Moisture content positively correlated with microbial population i.e.

microbial population's increases with temperature and moisture within a certain range which under optimum moisture and temperature condition, a given soil will support certain number of organisms of a typical soil. (Wilkinson *et al.*, 2002). Both bacteria and fungi showed a positive reaction to soil moisture (Bissit and Parkinson, 1979; Soderstrom 1979; Clarholm and Rosswall, 1980; Schimel *et al.*, 1999). Soil pH is acidic in nature which is generally linked with decrease rate of organic matter decomposition (Alexander 1980) although the extent of the decreased varies with the nature of the organic materials.

The high organic carbon in spring and rainy season could be attributed to the favourable growth of microorganisms which leads to high microbial activity through decomposition process. High organic carbon at the surface soil layer may be attributed to high microbial activity and accumulation of organic matter at this layer and less at the subsurface soil layer (Brown *et al.*, 1994 and Singh *et al.*, 1995). Accumulation of organic matter tends to be more in the sacred groves, thus high organic carbon. Soil organic matter input to minerals soil under *Pinus khasiana* stand were lower than those under the indigenous vegetation and would eventually result in lower total organic carbon levels as shown in the investigation.

High N, P and K content at the surface soil layer may be attributed to the high concentration of organic matter and dense microbial population, conditions in which nutrients remain immobilized. Maximum value of total N and available P was obtained in rainy season. Singh *et al.*, (1989) also found

maximum levels of N and P during rainy season. This was attributed to microbial activity and to reduced plant growth curtailing the demand for nutrients. The low levels of total N and available P during winter corresponded to a lower microbial population and low activity levels (Jha *et al.*, 1992). Nutrients mineralized by soil microorganism are immediately absorbed by plant roots and nutrient losses from the system are small. In tropical forest, temporal variation in fungal and microbial biomass can potentially alter the fate of nutrients in the ecosystem (Lodge *et al.*, 1994; Zimmerman *et al.*, 1995).

Analysis of the microbial biomass carbon showed that it is more in the sacred groves than in pine forest. This could be due to increased litter production in the sacred groves. The high microbial biomass C in the surface soil layer could be attributed to the increase in organic matter and nutrients (Ross *et al.*, 1982). Decrease in microbial biomass C with soil depth could be due to the reduction of organic matter and other nutrients (Lavahun *et al.*, 1996). Both the sacred groves the microbial biomass C is higher in spring and summer which corresponded to high soil moisture (Wardle and Parkinson, 1990). Powlson *et al.* (1987) reported that soil microbial biomass, the most active fraction of soil organic matter, responds rapidly to changes in the soil environment. The increased in soil organic carbon availability is likely to explain higher value of microbial biomass carbon, as C has been reported to be the principal energy source of soil microorganisms (Cleveland *et al.*, 2004, Demoling *et al.*, 2007).

Enzyme activities were higher in sacred groves than in pine forest. Changes in enzyme activities during the study period could have been partly associated with changes in soil moisture content (Speir and Ross, 1978). Increased enzyme activity at the surface layer (0-10cm) is also supported by Emmerling *et al.*, (2002) who stated that with increased organic matter there is an increased of microbial population which led to greater enzyme synthesis and accumulation in the soil matrix. Lower may result in reduced potential of the microbial community for enzyme synthesis and thus lower enzyme activities.

The high concentration of dehydrogenase, urease and phosphatase enzymes in sacred groves was due to high organic carbon and microbial populations. Seasonal fluctuation of the enzymes were observed in all the three forest stands which could be due to the seasonal changes in the environment which has brought about the different changes in the microbial population thus affecting the enzyme activity. The climatic and edaphic factors of soil may also influence the microbial enzymes (Harrison, 1979; Von Merici and Schinner, 1999).

Steady decrease in microbial activities with increasing depth was found in all the profiles in the forest stands with high activities in the surface soil layer (0-10cm). This finding is typical of profiles to be expected in the soil ecosystem that has develop over many years and has remain essentially and undisturbed over time. Organic matter incorporation into the surface layers and oxygen depletion in the deeper layers has lead to microbial activity in the

surface soil layer as compared to sub-surface layer (10-20cm and 20-30cm) as reported by Harris and Birch (1990).

The increase in dehydrogenase activity in rainy season was related to high nitrogen content, organic C and increased bacterial and fungal population numbers. The decrease in winter months may have been due to water stress condition (Dormaar *et al.*, 1984). Dehydrogenase activity correlates with total nitrogen, organic carbon, soil moisture content, microbial biomass C, fungal and bacterial population. Tiwari *et al.* (2002) reported that soil moisture content, fungal and bacterial population are the main factor which determined the dehydrogenase activity in the soil.

Phosphatase activity was maximum in rainy and minimum in winter. This observation agrees with that of Harrison (1979) who also obtained seasonal variation in phosphatase activity. There is a variation of phosphatase activity in all the forest stands. Increased production of phosphatase by plant roots and by microorganisms can be induced when P is limiting. Consequently, an increase in phosphatase activity reflect a high demand for P. Differences in seasonal phosphatase activity can be partially attributed to differences in the availability of substrate and P demand throughout the year (Schneider *et al.*, 2001). This supported the finding that phosphatase activity was high while phosphorus was low during the study period. No correlation was found between phosphatase activity with fungal and bacterial populations in Khloo Langdoh, and with fungal population in Khloo Paiung which was supported by Quiquampoix and Mousain (2005) who

reported that plants are also an important source of phosphatase enzyme in forest soils.

Decline of phosphatase activity with depth, like most other enzymes, was also reported by Tiwari, (1996). This decline could also be attributed to amount of moisture as reported by Daraseliya *et al.*(1975) that phosphatase activity often appears to be higher in saturated soils than in dry soils, or soils with normal amounts of moisture.

Urease activity was more in rainy season and a positive correlation was obtained with organic carbon and microbial population (Speir, 1977 and O'Toole *et al.*, 1985). The increased organic carbon in rainy season favours the growth of the soil microbial population. Urease activity was significantly correlated with organic C and total nitrogen (Frankenberger and Dick, 1983). Decrease of urease activity with soil depth could be due to decrease organic matter content and microbial population which is in opposite to surface soil layer.

Although a complete quantification of the number of microbial species in any one locality is difficult to obtain for several reasons, however, the result revealed that out of the 90 fungal species, *Aspergillus sp*, *Penicillium sp*, *Oidiodendron sp* and *Trichoderma sp* were the dominant species. *Alternaria tenuissima*, *Broomella acuta*, *Papula spora*, *Penicillium rubrum*, *Zygorrhynchus heterogamous*, *Scopulariopsis brevicaulis* & *Trichoderma sp* were isolated only in Khloo Paiung. While, *Alterneria altinata*, *Cylindrocarpon didymum*, *Oidiodendron rhodogenum*, *Preussia fumiculata*, *Penicillium*

herquiei and *P. ilandicum* were isolated in Khloo Langdoh. The species like *Broomellá acuta*, *Papula spora* and *Preussia fumiculata* are rarely isolated from Meghalaya. Among the bacterial species, *Micrococcus sp*, *Arthrobacter sp* and *Rhizobium sp* were the dominant species.

The sacred groves showed variation in species diversity compared to pine forest even though the difference is not so highly significant. Maturity of the plant community itself in both the sacred groves reflects an increased in soil organic carbon, nitrogen, microbial biomass carbon and other activities thereby supporting increased diversity of the soil microflora in the sacred groves.

Hence, it can be concluded that in soil a wide range of factors affect microbial life. Plant type and soil type; exert their effect in a complex manner. The soil and plant type is the major determining factor affecting the soil microbial community may relate to the effects being either stronger or weaker in accordance with the relative strength of the selective force exerted by soil or the plant. Also, this determining factor may be related to the complex microbial interactions in soil, including interactions between microorganisms and soil and microorganisms and plants. The microorganisms are also governed by a set of environmental factors and nutrients status present in the soil. While a number of factors may concomitantly cause the differentiations of soil microbial communities, our data suggest that resource availability is the primary control on microbial community composition within the soil.

Table 6.1. One way analysis of variance (ANOVA) of physico-chemical properties of soil with biological and biochemical properties of soil at surface and sub-surface layers in Khloo Paiung ($P \leq 0.001$)

Soil properties	Source of variance	F ratio	P level
Moisture content	0-10cm x 10-20cm	-	-
	0-10cm x 10-20cm x 20-30cm	6.26	2.693×10^{-3}
	0-10cm x 20-30cm	12.02	9.01×10^{-4}
	10-20cm x 20-30cm	-	-
pH	0-10cm x 10-20cm	-	-
	0-10cm x 10-20cm x 20-30cm	-	-
	0-10cm x 20-30cm	-	-
	10-20cm x 20-30cm	-	-
Organic carbon	0-10cm x 10-20cm	44.49	1×10^{-8}
	0-10cm x 10-20cm x 20-30cm	65.21	1×10^{-8}
	0-10cm x 20-30cm	107.39	1×10^{-8}
	10-20cm x 20-30cm	23.82	6×10^{-6}
Total nitrogen	0-10cm x 10-20cm	32.45	1×10^{-6}
	0-10cm x 10-20cm x 20-30cm	60.70	1×10^{-8}
	0-10cm x 20-30cm	111.50	1×10^{-6}
	10-20cm x 20-30cm	31.43	1×10^{-6}
Available phosphorus	0-10cm x 10-20cm	12.64	6.79×10^{-4}
	0-10cm x 10-20cm x 20-30cm	27.04	1×10^{-6}
	0-10cm x 20-30cm	47.36	1×10^{-6}
	10-20cm x 20-30cm	21.47	1.6×10^{-5}
Exchangeable potassium	0-10cm x 10-20cm	13.06	5.62×10^{-4}
	0-10cm x 10-20cm x 20-30cm	12.83	1.0×10^{-5}
	0-10cm x 20-30cm	24.71	5×10^{-6}
	10-20cm x 20-30cm	-	-
Microbial biomass C	0-10cm x 10-20cm	9.11	3.539×10^{-3}
	0-10cm x 10-20cm x 20-30cm	17.66	1×10^{-6}
	0-10cm x 20-30cm	33.05	1×10^{-6}
	10-20cm x 20-30cm	9.37	3.121×10^{-3}
Urease	0-10cm x 10-20cm	-	-
	0-10cm x 10-20cm x 20-30cm	-	-
	0-10cm x 20-30cm	-	-
	10-20cm x 20-30cm	-	-
Dehydrogenase	0-10cm x 10-20cm	25.77	3×10^{-8}
	0-10cm x 10-20cm x 20-30cm	32.99	1×10^{-6}
	0-10cm x 20-30cm	67.018	1×10^{-6}
	10-20cm x 20-30cm	7.60	7.431×10^{-3}
Phosphatase	0-10cm x 10-20cm	13.44	4.74×10^{-4}
	0-10cm x 10-20cm x 20-30cm	21.57	1×10^{-6}
	0-10cm x 20-30cm	44.55	1×10^{-6}
	10-20cm x 20-30cm	7.41	8.145×10^{-3}
Bacterial population	0-10cm x 10-20cm	21.02	1.9×10^{-5}
	0-10cm x 10-20cm x 20-30cm	42.28	1×10^{-6}
	0-10cm x 20-30cm	71.49	1×10^{-6}
	10-20cm x 20-30cm	28.90	1×10^{-6}
Fungal population	0-10cm x 10-20cm	-	-
	0-10cm x 10-20cm x 20-30cm	5.66	4.589×10^{-3}
	0-10cm x 20-30cm	9.83	2.509×10^{-3}
	10-20cm x 20-30cm	-	-

Note: Insignificant values are marked with ‘-’ sign.

Table 6.2. One way analysis of variance (ANOVA) of physico-chemical properties of soil with biological and biochemical properties of soil at surface and sub-surface layers in Khloo Langdoh ($P \leq 0.001$)

Soil properties	Source of variance	F ratio	P Level
Moisture content	0-10cm x 10-20cm	5.23	2.5220×10^{-2}
	0-10cm x 10-20cm x 20-30cm	3.71	2.7601×10^{-2}
	0-10cm x 20-30cm	5.51	2.1731×10^{-2}
	10-20cm x 20-30cm	-	-
pH	0-10cm x 10-20cm	-	-
	0-10cm x 10-20cm x 20-30cm	-	-
	0-10cm x 20-30cm	-	-
	10-20cm x 20-30cm	-	-
Organic carbon	0-10cm x 10-20cm	33.50	1×10^{-6}
	0-10cm x 10-20cm x 20-30cm	44.07	1×10^{-6}
	0-10cm x 20-30cm	76.74	1×10^{-6}
	10-20cm x 20-30cm	11.77	1.013×10^{-3}
Total nitrogen	0-10cm x 10-20cm	27.06	2×10^{-6}
	0-10cm x 10-20cm x 20-30cm	59.00	1×10^{-6}
	0-10cm x 20-30cm	117.71	1×10^{-6}
	10-20cm x 20-30cm	35.21	1×10^{-6}
Available phosphorus	0-10cm x 10-20cm	26.45	2×10^{-6}
	0-10cm x 10-20cm x 20-30cm	21.27	1×10^{-6}
	0-10cm x 20-30cm	26.18	3×10^{-6}
	10-20cm x 20-30cm	-	-
Exchangeable potassium	0-10cm x 10-20cm	28.64	1×10^{-6}
	0-10cm x 10-20cm x 20-30cm	28.90	1×10^{-6}
	0-10cm x 20-30cm	35.50	1×10^{-6}
	10-20cm x 20-30cm	-	-
Microbial biomass C	0-10cm x 10-20cm	21.33	1.7×10^{-5}
	0-10cm x 10-20cm x 20-30cm	49.92	1×10^{-6}
	0-10cm x 20-30cm	99.36	1×10^{-6}
	10-20cm x 20-30cm	32.61	1×10^{-6}
Urease	0-10cm x 10-20cm	-	-
	0-10cm x 10-20cm x 20-30cm	4.86	9.562×10^{-3}
	0-10cm x 20-30cm	9.84	2.494×10^{-3}
	10-20cm x 20-30cm	-	-
Dehydrogenase	0-10cm x 10-20cm	15.48	1.94×10^{-4}
	0-10cm x 10-20cm x 20-30cm	23.61	1×10^{-6}
	0-10cm x 20-30cm	47.69	1×10^{-6}
	10-20cm x 20-30cm	7.67	7.171×10^{-3}
Phosphatase	0-10cm x 10-20cm	7.97	6.187×10^{-3}
	0-10cm x 10-20cm x 20-30cm	8.55	3.60×10^{-4}
	0-10cm x 20-30cm	16.33	1.35×10^{-4}
	10-20cm x 20-30cm	-	-
Bacterial population	0-10cm x 10-20cm	21.37	1.7×10^{-5}
	0-10cm x 10-20cm x 20-30cm	32.47	1×10^{-6}
	0-10cm x 20-30cm	54.19	1×10^{-6}
	10-20cm x 20-30cm	13.58	4.46×10^{-4}
Fungal population	0-10cm x 10-20cm	20.21	2.7×10^{-5}
	0-10cm x 10-20cm x 20-30cm	14.25	3×10^{-6}
	0-10cm x 20-30cm	20.92	2.0×10^{-5}
	10-20cm x 20-30cm	-	-

Note: Insignificant values are marked with ‘-’ sign.

Table 6.3. One way analysis of variance (ANOVA) of physico-chemical properties of soil with biological and biochemical properties of soil at surface and sub-surface layers in Pine forest ($P \leq 0.001$).

Soil properties	Source of variance	F ratio	P Level
Moisture content	0-10cm x 10-20cm	-	-
	0-10cm x 10-20cm x 20-30cm	-	-
	0-10cm x 20-30cm	-	-
	10-20cm x 20-30cm	-	-
pH	0-10cm x 10-20cm	-	-
	0-10cm x 10-20cm x 20-30cm	-	-
	0-10cm x 20-30cm	-	-
	10-20cm x 20-30cm	-	-
Organic carbon	0-10cm x 10-20cm	88.34	1×10^{-6}
	0-10cm x 10-20cm x 20-30cm	96.59	1×10^{-6}
	0-10cm x 20-30cm	171.64	1×10^{-6}
	10-20cm x 20-30cm	10.23	1×10^{-6}
Total nitrogen	0-10cm x 10-20cm	51.33	1×10^{-6}
	0-10cm x 10-20cm x 20-30cm	50.99	1×10^{-6}
	0-10cm x 20-30cm	91.13	1×10^{-6}
	10-20cm x 20-30cm	4.53	3.6816×10^{-2}
Available phosphorus	0-10cm x 10-20cm	11.24	1.290×10^{-3}
	0-10cm x 10-20cm x 20-30cm	17.79	1×10^{-6}
	0-10cm x 20-30cm	33.08	1×10^{-6}
	10-20cm x 20-30cm	6.44	1.3381×10^{-2}
Exchangeable potassium	0-10cm x 10-20cm	-	-
	0-10cm x 10-20cm x 20-30cm	7.06	1.325×10^{-3}
	0-10cm x 20-30cm	13.65	4.33×10^{-4}
	10-20cm x 20-30cm	4.95	2.9273×10^{-2}
Microbial biomass C	0-10cm x 10-20cm	39.54	1×10^{-6}
	0-10cm x 10-20cm x 20-30cm	50.68	1×10^{-6}
	0-10cm x 20-30cm	112.05	1×10^{-6}
	10-20cm x 20-30cm	11.63	1.081×10^{-3}
Urease	0-10cm x 10-20cm	-	-
	0-10cm x 10-20cm x 20-30cm	-	-
	0-10cm x 20-30cm	-	-
	10-20cm x 20-30cm	-	-
Dehydrogenase	0-10cm x 10-20cm	12.29	7.98×10^{-4}
	0-10cm x 10-20cm x 20-30cm	28.02	1×10^{-6}
	0-10cm x 20-30cm	56.95	1×10^{-6}
	10-20cm x 20-30cm	15.71	1.76×10^{-4}
Phosphatase	0-10cm x 10-20cm	-	-
	0-10cm x 10-20cm x 20-30cm	7.08	1.303×10^{-3}
	0-10cm x 20-30cm	13.48	4.66×10^{-4}
	10-20cm x 20-30cm	4.74	3.2807×10^{-2}
Bacterial population	0-10cm x 10-20cm	7.64	7.273×10^{-3}
	0-10cm x 10-20cm x 20-30cm	14.17	4×10^{-6}
	0-10cm x 20-30cm	26.75	2×10^{-6}
	10-20cm x 20-30cm	7.22	8.982×10^{-3}
Fungal population	0-10cm x 10-20cm	6.23	1.4877×10^{-2}
	0-10cm x 10-20cm x 20-30cm	15.93	1×10^{-6}
	0-10cm x 20-30cm	40.99	1×10^{-6}
	10-20cm x 20-30cm	8.54	4.655×10^{-3}

Note: Insignificant values are marked with '–' sign.

Table.6.4. One way analysis of variance (ANOVA) of physico-chemical properties of soil with biological and biochemical properties of soil at surface and sub-surface layers in three forest stands.

Soil properties	Source of variance	0-10cm	10-20cm	20-30cm
Moisture content	KP X KL	10.03272 ^a	12.08730 ^a	9.71056 ^a
	KP X P	26.46418 ^a	31.03110 ^a	19.33741 ^a
	KL X P	6.28391 ^a	4.42800 ^b	4.50779 ^b
pH	KP X KL	7.41176 ^a	2.65399 ^c	10.83525 ^a
	KP X P	4.93190 ^b	13.24493 ^a	8.68690 ^a
	KL X P	12.72990 ^a	2.75043 ^c	23.16768 ^a
Organic carbon	KP X KL	5.95994 ^b	4.36383 ^b	8.57635 ^a
	KP X P	8.39836 ^a	11.31572 ^a	17.91954 ^a
	KL X P	7.41402 ^a	17.47525 ^a	23.14034 ^a
Total nitrogen	KP X KL	6.95497 ^a	4.58825 ^b	7.96387 ^a
	KP X P	9.59019 ^a	9.22747 ^a	10.47092 ^a
	KL X P	15.72617 ^a	12.43652 ^a	12.71033 ^a
Available phosphorus	KP X KL	4.15884 ^b	5.17539 ^b	1.70283 ^c
	KP X P	4.25964 ^b	2.97817 ^c	3.23442 ^c
	KL X P	1.78330 ^c	2.95314 ^c	1.46553 ^c
Exchangeable potassium	KP X KL	8.18999 ^a	3.44333 ^c	4.80481 ^b
	KP X P	5.09241 ^b	2.48725 ^c	3.82919 ^c
	KL X P	5.93730 ^b	2.75043 ^c	7.91099 ^a
Microbial biomass carbon	KP X KL	6.16508 ^a	6.24641 ^a	7.64434 ^a
	KP X P	17.06835 ^a	16.90857 ^a	10.79502 ^a
	KL X P	6.85682 ^a	4.72605 ^b	2.73445 ^c
Urease	KP X KL	5.04471 ^b	3.39562 ^c	2.54714 ^c
	KP X P	5.52327 ^b	3.63145 ^c	2.59540 ^c
	KL X P	5.62710 ^b	5.26813 ^b	3.93764 ^c
Dehydrogenase	KP X KL	7.17149 ^a	6.78072 ^a	31.28201 ^a
	KP X P	8.30004 ^a	6.31418 ^a	13.62326 ^a
	KL X P	5.63397 ^b	8.53609 ^a	9.91114 ^a
Phosphatase	KP X KL	20.53319 ^a	17.73756 ^a	16.00723 ^a
	KP X P	27.52359 ^a	20.17996 ^a	22.52149 ^a
	KL X P	18.63839 ^a	22.39740 ^a	15.56295 ^a
Bacterial population	KP X KL	21.03940 ^a	32.31566 ^a	15.11081 ^a
	KP X P	17.97643 ^a	20.42643 ^a	9.99183 ^a
	KL X P	16.38427 ^a	11.05462 ^a	13.22787 ^a
Fungal population	KP X KL	3.78851 ^c	1.80416 ^c	1.99260 ^c
	KP X P	5.23661 ^b	2.30276 ^c	2.92845 ^c
	KL X P	2.25195 ^c	3.59430 ^c	2.22450 ^c

Note: (KP = Khloo Paiung, KL = Khloo Langdoh and P = Pine forest)

Values are marked with a, b and c are significant at $P \leq 0.05$, $P \leq 0.01$ & $P \leq 0.001$ respectively.

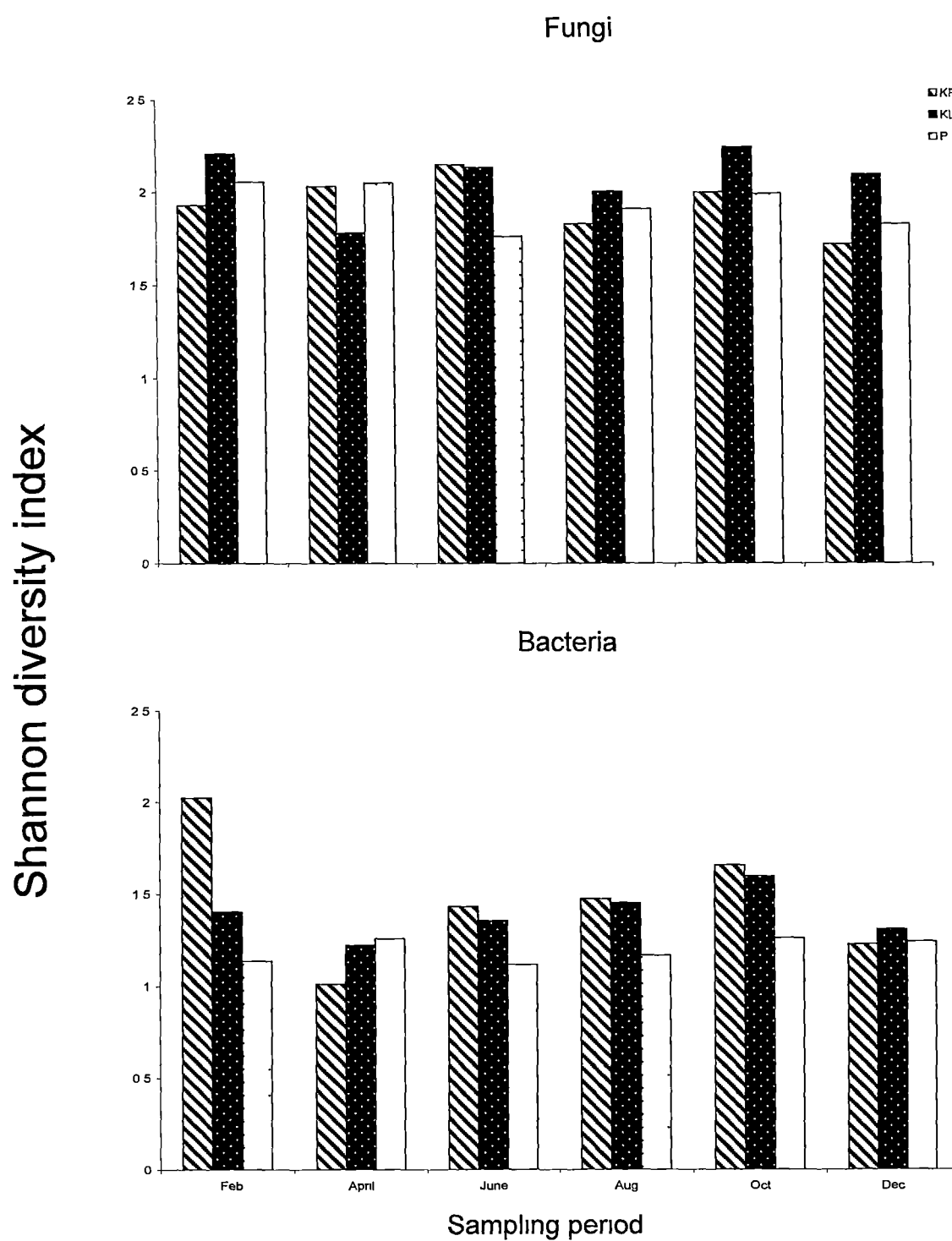


Fig. 6.1. Shannon diversity index of fungi and bacteria in soil of two sacred groves (Khloo Paiung, Khloo Langdoh) and Pine Forest (2002 and 2003).

Table 6.5. Correlation co-efficient (r) values among microbial population, with various biological, biochemical and physico-chemical properties of soil in the forest stand (Khloo Paiung) at surface layer and sub surface soil layer. ($P \leq 0.05$).

Soil properties	TN	AP	K	OC	C _{mic}	URA	DHA	PA	MC	pH	BP	FP
TN	-	0.5215 ^c	0.3496 ^a	0.7947 ^c	0.4939 ^b	-	0.6628 ^c	0.3906 ^a	0.5723 ^c	-	0.7242 ^c	0.3313 ^a
AP	0.5215 ^c	-	0.4196 ^b	0.7321 ^c	-	-	-	0.4834 ^b	-	-	0.3339 ^a	-
K	0.3496 ^a	0.4196 ^b	-	0.4966 ^b	0.5418 ^c	-	-	-	-	-	-	-
OC	0.7947 ^c	0.7321 ^c	0.4966 ^b	-	0.6055 ^c	-	0.4069 ^b	0.3648 ^a	-	-	0.5741 ^c	0.3970 ^a
C _{mic}	0.4939 ^b	-	0.5418 ^c	0.6055 ^c	-	0.3309 ^a	-	-	-	-	-	-
URA	-	-	-	-	0.3309 ^a	-	-	0.4504 ^b	-	-	-	0.3880 ^a
DHA	0.6628 ^c	-	-	0.4069 ^b	-	-	-	-	0.7490 ^c	-	0.7992 ^c	0.3778 ^a
PA	0.3906 ^a	0.4834 ^b	-	0.3648 ^a	-	0.4504 ^b	-	-	-	-	0.4290 ^a	-
MC	0.5723 ^c	-	-	-	-	-	0.7490 ^c	-	-	-	0.7999 ^c	0.3880 ^a
pH	-	-	-	-	-	-	-	-	-	-	-	-
BP	0.7242 ^c	0.3359 ^a	-	0.5741 ^c	-	-	0.7992 ^c	0.4290 ^b	0.7999 ^c	-	-	0.4191 ^b
FP	0.3313 ^a	-	-	0.3970 ^a	-	0.3380 ^a	0.3778 ^a	-	0.3800 ^b	-	0.4191 ^b	-

Note: TN = Total nitrogen, AP = Available phosphorus, K = Exchangeable potassium, OC = Organic carbon, C_{mic} = Microbial biomass carbon, URA = Urease activity, DHA = Dehydrogenase activity, PA = Phosphatase activity, MC = Moisture content, BP = Bacterial population, FP = Fungal population. Values marked with a, b and c are significant at $P \leq 0.05$, $P < 0.01$ and $P \leq 0.001$ respectively, insignificant values are marked with '- '.

Table 6.6. Correlation co-efficient (r) values among microbial population, with various biological, biochemical and physico-chemical properties of soil in the forest stand (Khloo Langdoh) at surface layer and sub surface soil layer. (P ≤ 0.05).

Soil properties	TN	AP	K	OC	C _{mic}	URA	DHA	PA	MC	pH	BP	FP
TN	-	-	-	0.5995 ^c	-	-	0.6413 ^c	0.3814 ^a	0.4339 ^b	-	0.5499 ^c	0.5056 ^c
AP	-	-	0.5093 ^c	0.3679 ^a	0.6421 ^c	-	-	-	-	-	-	-
K	-	0.5093 ^c	-	0.4381 ^b	0.4364 ^b	-	-	-	0.3491 ^a	-	-	-
OC	0.5995 ^c	0.3679 ^a	0.4381 ^b	-	0.4893 ^b	-	0.4441 ^b	-	-	-	0.3510 ^a	-
C _{mic}	-	0.6421 ^c	0.4364 ^b	0.4893 ^b	-	-	0.4250 ^b	-	-	-	0.5100 ^c	0.3876 ^a
URA	-	-	-	-	-	-	0.4677 ^b	0.5043 ^c	-	-	0.4920 ^b	-
DHA	0.6413 ^c	-	-	0.4441 ^b	0.4250 ^b	0.4677 ^b	-	0.4243 ^b	0.7334 ^c	-	0.6779 ^c	-
PA	0.3814 ^a	-	-	-	-	0.5043 ^c	0.4243 ^b	-	-	-	-	-
MC	0.4339 ^b	-	0.3491 ^a	-	-	-	0.7334 ^c	-	-	-	0.5845 ^c	0.4935 ^b
pH	-	-	-	-	-	-	-	-	-	-	-	-
BP	0.5499 ^c	-	-	0.3510 ^a	0.5100 ^c	0.4920 ^b	0.6779 ^c	-	0.5845 ^c	-	-	0.4467 ^b
FP	0.5056 ^c	-	-	-	0.3876 ^a	-	-	-	0.4935 ^b	-	0.4467 ^b	-

Note: TN = Total nitrogen, AP = Available phosphorus, K = Exchangeable potassium, OC = Organic carbon, C_{mic} = Microbial biomass carbon, URA = Urease activity, DHA = Dehydrogenase activity, PA = Phosphatase activity, MC = Moisture content, BP = Bacterial population, FP = Fungal population. Values marked with a, b and c are significant at P ≤ 0.05, P < 0.01 and P ≤ 0.001 respectively, insignificant values are marked with '-'.

CHAPTER 7

SUMMARY

The present research investigation deals with bimonthly enumeration and isolation of soil fungi and bacteria, microbial biomass C, enzymes activities and soil physico-chemical characteristic. The investigation was carried out at two sacred groves (Khloo Langdoh and Khloo Paiung) and pine forest of Jaintia Hills Meghalaya situated at Jowai the head quarter of Jaintia Hills, which is 60km away from Shillong.

The geographical position of Jowai is at 25° 26' 32" N Latitude, and 29° 12' E Longitude and situated at 1300m asl. The average maximum and minimum temperature during the study period was recorded are 25°C and 13.1°C in 2002 and 26°C and 14°C in 2003 respectively. The average rainfall was 360.6mm in 2002 and 265.2mm in 2003. The month of June was recorded the higher rainfall in both the years (i.e. 1283.8mm and 1178.6mm respectively). The soil samples were collected from three soil depths, (0-10cm, 10-20cm, 20-30cm), and the soil were analyzed for a variety of physical and chemical characteristics.

The fungal populations were higher in sacred groves than in the pine forest. In the first year (2002) of study, maximum fungal population was observed in rainy season in June and October and minimum in winter season in February and December in both the sacred groves. The fungal population in most cases is generally high at the surface soil layer (0-10cm) than at the sub

surface soil layer (10-20cm and 20-30cm). In the second year (2003) of study, maximum fungal population showed in April and August in Khloo Paiung and minimum in December in both the sacred groves. In both the years (2002 and 2003) the fungal populations were lower in pine forest in comparison to the sacred groves.

The investigation also showed that there is a declined of soil fungal population with soil depths. The population is higher at the surface soil layer (0-10cm) and lower at the sub surface soil layer (10-20cm, 20-30cm). In Khloo Paiung fungal population showed positive correlation with total nitrogen, organic carbon, urease activity, dehydrogenase, moisture content and bacterial population. In Khloo Langdoh it showed positive correlation with total nitrogen, microbial biomass carbon, moisture content and bacterial population. In pine forest it showed positive correlation with total nitrogen, organic carbon, microbial biomass carbon, dehydrogenase, phosphatase activity moisture content and bacterial population.

All together 90 fungal species and 5 sterile mycelia were isolated (75 species = Khloo Paiung, 66 species = Khloo Langdoh and 59 species= Pine forest) and out of these, *Aspergillus* sp, *Penicillium* sp, *Oidiodendron* sp and *Trichoderma* sp. were the dominant species, *Alternaria tenuissima*, *Broomella acuta*, *Papula spora*, *Penicillium rubrum*, *Zygorrhynchus heterogamous*, *Scopulariopsis brevicaulis*, were isolated from Khloo Paiung only, while *Alternaria alternata*, *Cylindrocarpon didymum*, *Oidiodendron rhodogenum*, *Preussia fumiculata*, *Penicillium herquiei* and *P. ilandicum* were isolated from

Khloo Langdoh only. 54 species are common to both the sacred groves, 46 species are common to Khloo Paiung and Pine forest, while 39 species are common to Khloo Langdoh and Pine. In general, high species diversity of fungi was noted in the two sacred groves than in the pine forest. In the first year (2002), diversity of fungi were high in Khloo Paiung, while in the second year (2003), high diversity of fungi were observed in Khloo Langdoh, except in few cases it showed some increase in pine forest. Similarity index showed a similar trend in all the three forest stands.

Bacterial population increased in rainy season in all the three forest stands. In the first year (2002), maximum bacterial population was observed in August and minimum in February in Khloo Paiung. In the second year (2003), maximum bacterial population in June in all the three forest stands and minimum in December in the two sacred groves and in August in the pine forest. Between the sampling periods the bacterial population declined with soil depth, which recorded highest population at the surface soil layer (0-10cm) and minimum population was recorded at the sub surface soil layer (10-20cm, 20-30cm).

In Khloo Paiung the bacterial population showed positive correlation with moisture content, organic carbon, total nitrogen, available phosphorus, dehydrogenase phosphatase and fungal population. In Khloo Langdoh the bacterial population showed positive correlation with moisture content, organic carbon, total nitrogen, microbial biomass carbon, dehydrogenase, urease and fungal population. In pine forest the bacterial population showed positive

correlation with total nitrogen, microbial biomass carbon, urease, phosphatase and fungal population. Altogether, 8 bacterial species were isolated *Microccus* sp, *Arthrobacter* sp and *Rhizobium* sp were the dominant species. In general diversity index of bacteria was noted in the two sacred groves. It was high at sub surface soil layer in June and October in Khloo Paiung in year first (2002). While, it was high at sub surface soil layer in February in pine forest in the second year (2003). Similarity index showed similar trend in all the three forest stands.

The soil moisture content was higher at the surface soil layer (0-10 cm) and lower at the subsurface soil layer (10-20cm & 20-30 cm). The soil pH ranged between 4.75 - 6.5 in all the depths (0-10cm, 10-20cm and 20-30cm), the soil pH showed negative correlation with all soil parameters.

Seasonal fluctuation of soil organic carbon was observed, where it was higher during warm season and lower during cold season. There is an increased percentage of organic carbon in both the sacred groves than in the pine forest. The organic carbon varied with soil depth as it tends to be more at the surface soil layer (0-10cm) than at the subsurface soil layer (10-20cm and 20-30cm). In Khloo Paiung the correlation coefficient values of soil moisture content showed a positive correlation with total nitrogen, available phosphorus potassium, microbial biomass carbon, dehydrogenase, phosphatase, bacterial population and fungal population. In Khloo Langdoh the correlation coefficient values of soil organic carbon showed a positive correlation with total nitrogen,

available phosphorus, potassium, microbial biomass carbon, dehydrogenase, and bacterial population

Organic carbon varied significantly ($P \leq 0.001$) at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in all the three forest stands.

Total nitrogen showed increased percentage in both sacred groves than in the pine forest. Peak percentage of total nitrogen was observed in August 2002 and October 2003. While it also showed peak percentage at the surface soil layer (0-10cm) than at subsurface soil layer (10-20cm and 20-30cm). The correlation coefficient values of soil moisture content showed a positive correlation with available phosphorus, potassium, organic carbon, microbial biomass carbon, dehydrogenase, phosphatase, moisture content, bacterial population and fungal population in Khloo Paiung. In Khloo Langdoh the correlation coefficient values of soil organic carbon showed a positive correlation with organic carbon, dehydrogenase, phosphatase, moisture content, bacterial population and fungal population. In pine forest the correlation coefficient values of soil organic carbon showed a positive correlation with available phosphorus, organic carbon, microbial biomass carbon, bacterial population and fungal population. Total nitrogen varied significantly at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in all the three forest stands.

The soil phosphorus is high in both sacred groves than in pine forest. Seasonal fluctuation was observed, where it was high in June and low in December in both the year but it was higher in the first year of study. Soil phosphorus was high at the surface soil layer (0-10cm) and low at the subsurface soil layer (10-20cm and 20-30cm). In Khloo Paiung the correlation coefficient values of available phosphorus showed a positive correlation with total nitrogen, potassium, organic carbon, phosphatase and bacterial population. In Khloo Langdoh the correlation coefficient values of available phosphorus showed a positive correlation with organic carbon, potassium and microbial biomass carbon. In pine forest the correlation coefficient values of available phosphorus showed a positive correlation with total nitrogen, organic carbon and microbial biomass carbon. Available phosphorus varied significantly with soil depth between 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in pine forest and Khloo Paiung and at 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20cm x 30cm in Khloo Langdoh.

Soil potassium showed more concentration in both sacred groves than in pine forest. It showed seasonal variation where it tends to be more in winter season and low in rainy season. In Khloo Paiung the correlation coefficient values of potassium showed a positive correlation with total nitrogen, available phosphorus organic carbon, and microbial biomass carbon. In Khloo Langdoh the correlation coefficient values of potassium showed a positive correlation with available phosphorus, organic carbon, microbial biomass carbon and

moisture content. In pine forest the correlation coefficient values of potassium showed a positive correlation with moisture content only. Soil potassium varied significantly with soil depth between 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm in Khloo Paiung and Khloo Langdoh and at 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm in pine forest.

The soil microbial biomass C increased in both sacred groves than in pine forest. Soil microbial biomass C declined from the surface soil layer (0-10cm) to the sub surface soil layer (10-20cm, 20-30cm). It showed seasonal variation where it is more in the spring or warm season and low in winter or cold season and rainy season in few cases. In Khloo Paiung soil microbial carbon was positively correlated with total nitrogen, potassium, organic carbon and urease. In Khloo Langdoh soil microbial carbon was positively correlated with available phosphorus, potassium, organic Carbon, dehydrogenase, bacterial population and fungal population. In pine forest soil microbial carbon was positively correlated with total nitrogen, available phosphorus, organic carbon, dehydrogenase, bacterial population and fungal population. Microbial biomass C varied significantly ($P \leq 0.001$) between 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm soil depths in Khloo Paiung between 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm soil depths in Khloo Langdoh and pine forest.

The activities of soil enzymes (dehydrogenase, urease and phosphatase) were quite similar in all the three forest stands, except in few

cases where it is more in the two sacred groves. Enzyme activities showed seasonal variation. It is high in rainy and low in winter season. It is more at the surface soil layer (0-10cm) than in the subsurface soil layer (10-20cm and 20-30cm). Dehydrogenase activity was high in June and August and low in February in 2002. In 2003 it was high in August and low in February and December in Khloo Paiung which is similar to that of Khloo Langdoh and pine forest. In Khloo Paiung dehydrogenase activity showed positive correlation with total nitrogen, organic carbon, soil moisture bacterial population and fungal population. In Khloo Langdoh it showed positive correlation with total nitrogen, Cmic, urease, phosphatases, and bacterial population. In pine forest it showed positive correlation with organic carbon, Cmic, and fungal population. Dehydrogenase activity varied significantly ($P \leq 0.001$) between 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm soil depths in all the three forest stands.

Phosphatase activity was high in June for Khloo Paiung and October for Khloo Langdoh and pine forest in 2002. In 2003 it showed high activity in October for Khloo Paiung and Khloo Langdoh and minimum in February. Phosphatase activity varied significantly ($P \leq 0.001$) between 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm and 0-10cm x 20-30cm soil depths in Khloo Langdoh, between 0-10cm x 10-20cm, 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm soil depths in Khloo Paiung and between , 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm and 10-20cm x 20-30cm soil depths in pine forest.

Urease activity was high in June in 2002 but low in February in 2002 and 2003 respectively for all the three forest stands. Urease activity is more at the surface soil layer (0-10cm) than at the subsurface soil layer (10-20cm) and (20-30cm). In Khloo Paiung, urease activity was positively correlated with C_{mic} , available phosphorus and fungal population. In Khloo Langdoh urease activity was positively correlated with dehydrogenase, available phosphorus and bacterial population. In pine forest, urease activity was positively correlated with bacterial population. Urease activity varied significantly ($P \leq 0.001$) between 0-10cm x 10-20cm x 20-30cm, 0-10cm x 20-30cm soil depths in Khloo Paiung. Insignificant variation in Khloo Langdoh and pine forest in all the soil depth.

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National Roving Seminar On Patenting in Biotechnology	Department of Biotechnology Ministry of Science & Technology, New Delhi	26 th October, 2002 Shillong	Participant
Workshop Cum- Seminar For Promotion Of Medicinal Plants Sector in Meghalaya	Meghalaya State Medicinal Plants Board, Shillong	10 th March, 2007 Shillong	Participant
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